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Boston Society of Natural History.

IV.

GEOLOGY OF THE BOSTON BASIN

BY

WILLIAM O. CROSBY.

VOL. I.

PART I.—NANTASKET AND COHASSET.

BOSTON:
BOSTON SOCIETY OF NATURAL HISTORY.
1893.

B. N.

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IV.

GEOLOGY OF THE BOSTON BASIN.

BY

WILLIAM O. CROSBY.

WITH THIRTY-EIGHT PLATES.

BOSTON:

PRINTED FOR THE SOCIETY.

1893–1900.

This work, "Geology of the Boston Basin," was originally planned to comprise two volumes of several parts each. Only the first three parts of the first volume, however, were completed by Prof. Crosby before his death. Plate 13, designed to accompany Part II, was never issued.

Title-page issued April, 1927.

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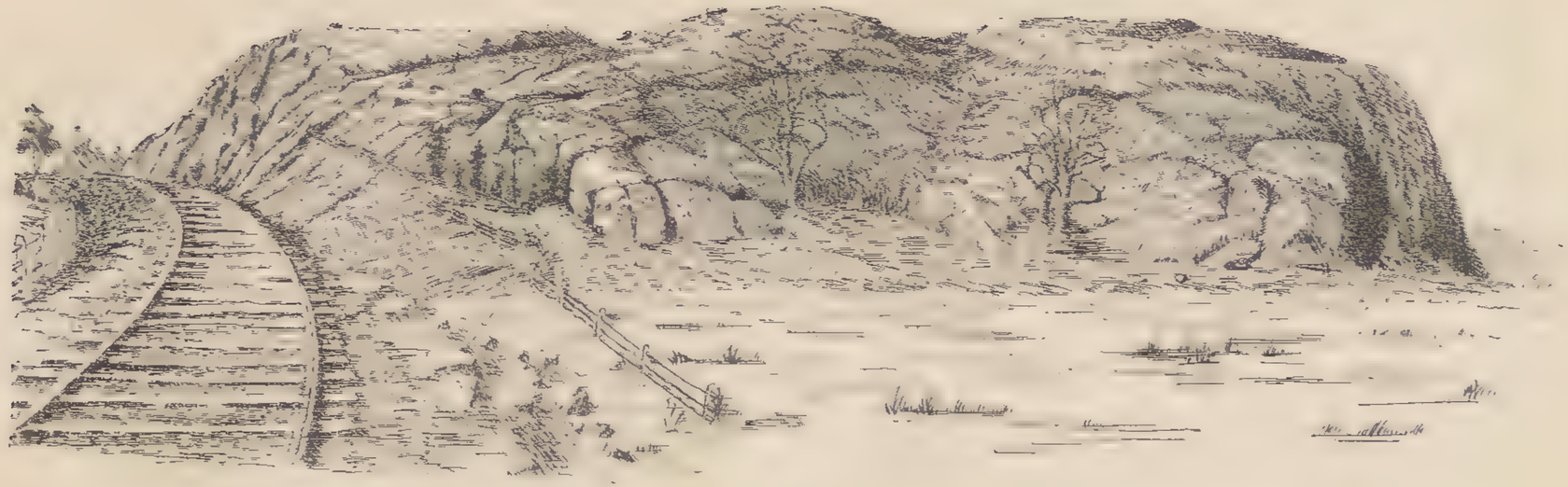

GREAT HILL SEEN FROM THE NORTH. A CHARACTERISTIC EXAMPLE OF NANTASKET TOPOGRAPHY.

GEOLOGY

OF THE

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BY

WILLIAM O. CROSBY.

IN TWO VOLUMES.

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The expense of publishing this part is defrayed chiefly by Mr. Thomas A. Watson.

NANTASKET AND COHASSET.

INTRODUCTION.

It is obvious upon the most casual observation that the town of Hull, Mass., which is virtually an island, being joined to the main land of Cohasset only by the narrow barrier beach connecting the Green Hill drumlin with the granite ledges along the Jerusalem Road, is sharply divided into two districts which are very strongly contrasted in their topographic and geologic features. In the order of geologic age and interest these are: (1) The highly irregular, broken and rocky tract, commonly known as Nantasket, which forms the southern extremity of the town, adjoining the main land, and is almost completely isolated by Strait's Pond, Weir River Bay, Nantasket Harbor and the Atlantic. (2) The narrow, and, at some points, extremely slender peninsula stretching from Atlantic Hill north-northwest for more than three miles to Point Allerton, whence, turning at a right angle, it extends to the westward two miles further to Pemberton and Windmill Point. This peninsula thus embraces Nantasket Beach and the Village of Hull; and, with the exception of the single ledge of slate on the south side of Thornbush Hill, near the Village, it is composed entirely of rounded drift hills or drumlins and the connecting beaches of sand and shingle. The dividing line between these two districts is where the sands of the beach rest against the rocky northern base of Atlantic Hill.

Although the main purpose of this paper is to set forth the results of a detailed study of the intricate geologic structure exhibited in the magnificent rock exposures of the southern area

(Nantasket), the concluding pages, especially, relating to the glacial and more recent phenomena and the non-lithified deposits of the district, will apply to the northern or beach area as well. Hence the scope of the paper really embraces the entire area of Hull, or Nantasket in the broad, original application of the name.[1] The mouth of Weir River, or Weir River Bay, forms, in the topographic sense, the natural western boundary of the Nantasket area; yet, geologically, it is impossible to exclude the promontory of Rocky Neck, in Hingham. This rocky headland is lithologically and structurally identical with the district east of Weir River Bay, while it is completely separated from the other and dissimilar sedimentary areas of Hingham by the ledges of granite on the south and southwest and the drumlins of Planter's Hill and World's End on the west and northwest. The natural boundary line between the geologic areas of Nantasket and northern Hingham appears, therefore, to be, not Weir River Bay but the eastern shore of Hingham Harbor. The southern boundary or limit of Nantasket is clearly marked by the continuous depression formed by Strait's Pond, Lyford's Liking and Weir River Bay, which is continued, as a narrow strip of marsh, south of Rocky Neck to the bay which sharply indents the eastern shore of Hingham Harbor. This topographic trough defines with approximate accuracy the present border of the Boston Basin, separating the sedimentary and volcanic rocks from the somewhat more elevated granitic area on the south.

Although the line of depression just traced is a natural and important geologic boundary, it has appeared best to give this paper greater breadth and completeness by including in its scope not only the sedimentary and volcanic rocks of Nantasket, and the granite floor upon which they rest, but also a sufficient breadth of the granitic border of the basin to make apparent the marked contrast in geologic structure on opposite sides of

[1]The outer islands of Boston Harbor (the Brewsters, Calf Id., Green Id., etc.) belong to the town of Hull. But the geology of these formed the subject of a previous paper (Proc. B. S. N. H., XXIII., 450–457); and will be more fully described in a later paper of this series.

the boundary. The geology, so far as the hard rocks are concerned, is as simple south of the line as it is complex north of it. Hence, although, as the map shows, the addition of the whole of Cohasset and a portion of Scituate much more than doubles the area to be described, it extends but slightly the limits of this paper, which is still, notwithstanding its title and areal scope, chiefly a detailed account of the ledges of Nantasket.

The numerous islands of Boston Harbor, as any one may observe in going from Boston to Nantasket by water, are, with unimportant exceptions, composed, like the Nantasket Beach area, wholly or almost wholly of rounded drift hills and connecting beaches of sand and gravel; and the fine sections of some of the drumlins due to marine erosion show that in most cases they are pure drift accumulations, at least above sea level. The Boston Basin does not afford a stronger topographic contrast than is presented when the Nantasket steamer, having rounded Bumkin Island, the graceful drumlin outline of which is abruptly terminated on the west by marine erosion, and followed the winding channel past the beautiful drumlins of the World's End and Planter's Hill, sweeps by the bold and massive ledges of Rocky Neck and Nantasket. We pass in an instant from an area which is deeply covered by drift and presents only the most typical drift-contours, to an essentially driftless area, where the ice-sheet left hardly sufficient detritus to fill the narrow gorges and chasms dividing the rocky hills.

The problem involved in this unequal distribution of the drift, in this abrupt passage from an area in which the ice-sheet acted, at least during its later stages, as an important agent of deposition, to an area in which its action was purely erosive, lies beyond the scope of this paper; although, if the drift had not been swept from the Nantasket area, there would have been little occasion for a special study of its geologic features. We may now simply accept the almost perfect exposures of these rock masses as one of the best gifts of the ice-sheet to the student of our local geology; for there is probably no equally limited area in the Boston Basin more worthy of detailed and thorough investigation than this southeast corner.

The structure of other districts is, no doubt, equally varied and intricate; but Nantasket excels in the very favorable opportunities which its almost continuous rock surfaces present for deciphering its structure lines. It is especially interesting, in this connection, to observe that, while the rocky area occurring next to the north of Nantasket, in the middle line or axis of the Boston Basin—the outer islands of Boston Harbor—affords the finest and most typical exposures of intrusive sheets or interbedded dikes to be found in this region; the characters of the contemporaneous beds or ancient lava flows of the Boston Basin and their relations to the interstratified conglomerate can be studied to the best advantage at Nantasket, on the border of the basin.

At no other point is the evidence equally clear and conclusive that the melaphyrs and porphyrites of the Boston Basin are, in the main, true contemporaneous lavas which were poured out on the sea-floor at different periods during the deposition of the beds of conglomerate and sandstone. The Nantasket area also shows more clearly than any other that in some parts, at least, of the Boston Basin the conglomerate beds, as well as the associated melaphyrs rest directly upon the fundamental granite, without the possible interposition of the slate series.

It may be pointed out in this connection that the main purpose of the present investigation is simply to elucidate the structure and explain the origin and sequence of the rocks of this somewhat complicated area. In other words, this is a structural rather than a lithological study; and I wish to acknowledge my great obligation to Mr. Geo. P. Merrill of the U. S. National Museum for undertaking a microscopic examination of the newer eruptive rocks of Nantasket. His determinations have prevented serious errors in my work and enabled me to draw certain conclusions with a degree of confidence which it would otherwise have been impossible to feel.

TOPOGRAPHY.

The rocky areas or ledges of Cohasset and Nantasket are characterized, considering their diversified geologic structure, by a remarkable uniformity of elevation, indicating that in preglacial times this region was worn down nearly if not quite to its base-level; and the deeply incised and generally abrupt character of the valleys now dividing this old peneplain shows that it must have shared in the general and marked elevation of the land at the dawn of the great ice age; while the fact that the deeper valleys are now to a large extent occupied by the sea or its deposits, *i. e.*, are or have been true fiords, is sufficient evidence of a subsequent subsidence; and, finally, the extensive beach and marsh formations prove that the present level of the land has been maintained for a very long time. The modern base-level is strongly accentuated, not alone through the constructive action of the sea, but marine erosion has made extensive inroads upon the drumlins and other drift deposits, especially of the Nantasket peninsula and adjacent islands, developing the prominent sea-cliffs of Telegraph Hill, Point Allerton, Strawberry and Green Hills, etc.,as well as broad submarine platforms or shoals, the outlines of which can be traced on the Coast Survey chart.

Since even the most typical peneplain must slope gently seaward, the average elevation of the rock-surface of eastern Massachusetts increases gradually as it recedes from the coast; and Nantasket and Cohasset are, therefore, one of the lower portions of it. In the valleys, the rock-contours are, of course, carried down to and below sea-level; but the ledges and rocky hills separating the depressions, the real remnants of the ancient peneplain, are, even in the Nantasket area and along the Cohasset shore, rarely below 50, and usually from 75 to 100 feet, in height; and the elevation, increasing very slightly inland, attains its maximum of 125 to, possibly, 150 feet in the broad

area of rocky woodland along the boundary between Cohasset and Hingham. The moderate disparity of these figures does not contradict the previous statement concerning the general uniformity of the rocky elevations; for the main point is that while there are hundreds of rocky hills and ridges or ledges rising 10 to 50 feet or more above the ground between them, there are none rising to commanding heights, that is, there are no rock elevations decidedly overlooking the surrounding country, as do the drift hills or drumlins. It is of course this absence of true rock hills that proves the ancient peneplain; for the present interstream surfaces, where not encumbered by drift, are essentially ledgy plateaus. The absence of crags and pinacles of rock is easily accounted for by the severe glaciation which this region has suffered; but we cannot thus explain the fact that there are no dominant rock hills of rounded or glaciated outline, like the Blue Hills. That glacial erosion was not equal to the complete obliteration of such reliefs is proved by the survival, even when quite isolated, of the numerous hills and ledges which do not rise above the surface of the dissected peneplain. Briefly stated, then, the rock hills of this district have all been carved out of the preglacial peneplain; and the general equality of relief thus determined must continue until an increased elevation of the land, giving renewed energy to the ordinary agents of erosion, permits a more general and unequal effacement of the original interstream surfaces.

That the depressions or valleys which now interrupt the peneplain are not due chiefly to glacial, but to preglacial aqueous, erosion is sufficiently obvious, in many cases, from their directions; and it is also seen in the fact that the rock hills and ledges of Nantasket and Cohasset, through the influence of the faults, dikes and joints by which they are bounded, are, in the main, approximately rectangular in plan, with, frequently, very steep or even precipitous slopes, and showing only secondarily, and not as their primary form, the *roche moutonée* outline due to glaciation. Hence, cliffs, sometimes rising abruptly from the water or the salt marshes, and straight, narrow defiles are

characteristic topographic features of the district, although the partial submergence of the valleys and the general plateau form of the hills causes the elevations to appear incommensurate with the otherwise rugged character of the topography. North of Atlantic Hill we descend into the great central valley of the Boston Basin, now occupied by Boston Harbor; and the peneplain is lost. This is an area of much softer, sedimentary rocks, which was deeply and broadly eroded, when the region was more elevated, by the united Charles and Neponset Rivers and their affluents.

The lower portions, especially, of the old peneplain, in Cohasset, are to a considerable extent emphasized by level expanses of modified drift. The principal sand plain, through which project both the drumlins and the higher ledges, ranges from 40 to 60 feet in height and extends interruptedly over a large part of the town, mantling but not greatly masking the contours of the underlying rocks. Although distinctly recognizable at many points, it has its finest development in and about Cohasset Village, between Little Harbor and the railroad, rising very abruptly 45 feet from the level marshes of Little Harbor to the kettle-dimpled plain on which the village stands. North of Strait's Pond and Weir River Bay, in Nantasket and northern Hull, the modified drift is very scantily developed and of no topographic importance. But in the terraces or elevated shore-lines traceable at corresponding heights on some of the drumlins in Hull and also in Cohasset and Scituate, and accurately marking the varying levels of the sea at the time when the sand plains were formed, we have a related feature of considerable interest which will, in its proper sequence, be described in detail.

While the modified drift is, at the best, only a minor factor in the topography of this district, the unmodified drift or till, on the other hand, occurring almost wholly in the form of drumlins, adds greatly to the topographic relief and diversity. The drumlins constitute, virtually, the only elevations in Hull north of Atlantic Hill; in fact it is doubtful if this part of the peninsula would have any existence as dry land if it were not

for these solid nuclei of till about which the beach deposits have gathered. As already noted, and as the map shows, the drumlins are not evenly distributed. In Hull, in the direct line of the beach, like a string of beads, are Point Allerton and Strawberry Hills, White Head, Sagamore Head, Hampton Hill, Rockland Hill (a lenticular slope of till) and Green Hill. Parallel with this line, on the west, is a second, including the drumlins of Hull Village — Thornbush and Telegraph Hills, Little Hog Island and Bumkin Island, this line being continued to the west of Nantasket in the double drumlin of the Worlds' End, Planters' Hill and Pine Hill. From either of these lines we pass to an area, including the Nantasket ledges and all that part of Cohasset and Hingham north of the railroad and east of Hingham Harbor, in which drumlins, or any noteworthy accumulations of till, are almost wholly wanting; the hard granite surface of the peneplain standing forth clear and naked. But south of the railroad, again, in the broad depressed or valley portion of Cohasset, the drumlins are thickly planted, greatly obscuring this portion of the peneplain. The series begins on the northwest with Turkey Hill (181 feet) and Scituate Hill (177 feet), two of the most typical drumlins in the Boston Basin and the culminating points of the area to which this paper relates. Southeastward, as the map shows, the belt broadens, but the drumlins, although more numerous, are also smaller and very much flatter in form, being, where they reach the level of the principal sand plain, as in Hoop Pole and Mann Hills, in Scituate, not readily distinguished from it. But farther south in Scituate, we find again, in Booth Hill, a drumlin of respectable height and great horizontal extent. West of King Street, Scituate Pond and the head waters of Bound Brook, and south of Turkey and Scituate Hills, no drumlins have been observed in Cohasset, the peneplain being here, as north of the railroad, but slightly encumbered by drift deposits.

The drainage of this district is a simple story. No part of Hull is more than one-fourth of a mile from the salt water, and

there are no streams. The plateau of North Cohasset drains directly by several short brooks, of which the most important is Turkey Hill Run, rising in the swamp between Turkey and Scituate Hills, into the Strait's Pond trough, the Atlantic and Little Harbor. The remainder of Cohasset and northern Scituate are tributary either to Cohasset Harbor and its extension, the Gulf, or to Bound Brook, which is the principal affluent of the Gulf. Considerable attention has been given to tracing out not only the actual drainage lines or streams, but also the areas of obstructed drainage, the ponds, swamps and marshes; and it is believed that these features are represented more accurately on the maps accompanying this paper than on any earlier published maps.

Besides Strait's Pond, which is due to an artificial barrier at its western end and is mainly salt water, the only important pond in this entire district of Hull, Cohasset and northern Scituate is Scituate Pond (sometimes called Lily Pond) in the southern central part of Cohasset. It is tributary to Bound Brook; and it is also connected on the northeast with a swampy tract from which a much smaller brook flows directly into the Gulf. Scituate Pond is thus very nearly an example of a basin having two distinct outlets at the same level or in a state of equilibrium. It is probably due primarily to the accumulation of modified drift in the valley of Bound Brook; and the general absence of ponds in this district may be attributed to the lack of continuity of the sand plains. Even the small kettle ponds of other districts, with a few exceptions, as in the vicinity of Little Harbor where the principal plain has its best development, are wanting here. Neither is the form of the ground favorable to the view that any important ponds have been obliterated by the cutting down of barriers or the growth of silt and bog deposits. If the valley of Bound Brook were cleared out, the Gulf would doubtless be extended inland to Scituate Pond, if not considerably beyond; and this main drainage channel and its affluents are now so nearly on a base-level basis that they are bordered throughout by broad swamps and meadows.

Besides Bound Brook and the Gulf, the principal submerged or drowned rock valleys of this district are Weir River Bay and Strait's Pond, Little Harbor, and Cohasset Harbor. These fiords, as remarked, are all far advanced in the process of silting up to the present level of the sea. Even Cohasset Harbor is a harbor in little more than name, presenting with the ebb of the tide a broad level expanse of mud and sand of great but undetermined thickness; while the widely extended marshes on the east and south show how greatly the area as well as the depth of the harbor has been reduced. The barrier beach bordering and limiting the salt marshes on the north has nearly separated the outer harbor from the Cove; and the soundings on the chart indicate that a similar bar is now forming across the mouth of the outer harbor, from the Glades westward. In more exposed situations, the sea has already closed by barrier beaches two eastern entrances to Cohasset Harbor, the main entrance to Little Harbor, the eastern end of Strait's Pond, and connected all the drumlins of the Nantasket peninsula by beaches from fifty feet to nearly half a mile in width. The numerous rocks and islets fringing this part of the coast are not the result of marine erosion; but these, and also the ledges, sometimes of great extent, now isolated by the salt marshes of Nantasket and Cohasset, testify equally with the submerged valleys to the subsidence of the land. Continued subsidence would submerge these ledges and isolate others, leaving the general aspect of the coast unchanged.

MAPS.

This paper is accompanied by two maps (Plates I and II). The first, on a scale of 2400 feet to the inch, embraces the entire peninsula of Hull, the whole of Cohasset, a portion of Scituate and all but the southern end of Hingham, or, in other words, the entire area to be described not only in this paper but also in the following paper on the geology of Hingham. Topographically, it is based primarily upon the Coast Survey chart of

Boston Harbor and the atlases of Plymouth and Norfolk Counties; but certain features, especially the marshes, drainage lines, drumlins and other drift reliefs have been greatly modified in accordance with original observations. The aim has been to compile the best obtainable data, rather than to preserve a uniform degree of accuracy, and undoubtedly some parts of the map are much more reliable than others. Even in the absence of contour lines, it exhibits some of the more important relief features, the kames and drumlins being clearly distinguished; while the hydography, including the shore-lines, ponds, streams, swamps and marshes, is represented with unusual completeness and accuracy; and it shows in addition the general structure of the hard rocks, and especially the relations of the granitic masses to the sedimentary and volcanic deposits. The Nantasket area, the elucidation of which is the special object in view, forms the central part of this first or general map, which thus illustrates its topographic and geologic relations to contiguous districts; while the second or special map, on a scale of 600 feet to the inch, permits of much greater detail.

No good or even approximately accurate topographic map of all that large part of the Nantasket district west of the County Road has heretofore been published, and it has been necessary to devote considerable time and labor to the preparation of a suitable basis for the representation of the geologic features. I am particularly indebted to Mr. Wm. M. Beaman for the substantial accuracy of the western area, between the railroad and Weir River Bay, and for a general triangulation of the entire district from Planter's Hill to Green Hill and Black Rock; and to Mr. Gordon H. Taylor for the contour lines upon nearly the entire map excepting the western area.[1]

The map of Rocky Neck is based upon the plan of a land survey kindly furnished by Mr. John R. Brewer; and the coastal area, from the steamboat wharf to Green Hill is re-

[1] Messrs. Beaman and Taylor have made a careful study of the topography of this section as students in the Department of Civil Engineering in the Massachusetts Institute of Technology.

duced, with some modifications, from the map of Nantasket in the atlas of Plymouth County, 1879; while I am personally responsible for the outlines of the central area, between the County Road and railroad, and for the entire south shore of Weir River Bay, Lyford's Liking and Strait's Pond.

The general absence of roads or other artificial land-marks west of Hull Street and the County Road, and especially west of the railroad, and the fact that the hills and other natural features in this section were still unnamed, caused it to appear desirable, in the interests of concise and intelligible description, to assign names to the more important rock masses, marshes, etc. Of course it is not expected that many if any of the geologic and descriptive designations which appear upon the map and in the following pages will gain general acceptance; and this is in no wise essential to their present usefulness. The actual exposures of the hard rocks are so nearly continuous over the areas where they are indicated by colors on this map that it has appeared unnecessary to represent the individual ledges or outcrops; although this is virtually done for all the ledges in the marshes and below the high-tide line. And, except in the case of some of the fault-lines, the map may be fairly regarded as a plain record of actually observed facts, devoid of theory.

THE GRANITIC ROCKS OF COHASSET.

This heading, in its broadest application, covers all the geological formations of Cohasset, except the dikes of diabase and porphyrite and the drift deposits. The dikes, being essentially similar in character and age to those of Nantasket will be most conveniently described in that connection; and since the superficial geology forms naturally one continuous chapter for the entire area to which this paper relates, the drumlins, sand plains, etc., of Cohasset will not be taken up separately. But it appears best to introduce a general account, lithological and structural, of the granitic rocks of Cohasset at this point, because they form,

not only the border, but the floor of this part of the Boston Basin. They are alike the foundation upon which the newer sediments and lavas of Nantasket are piled, and the principal source from which the material for building the Nantasket strata was derived.

Among the granitic rocks of Cohasset are included chiefly the diorite and the granite proper. The diorite is in every instance clearly the older, as well as the less abundant and less important, rock; the relations of the two rocks being essentially the same here as elsewhere about the Boston Basin. To a large extent they are quite intimately associated, the diorite occurring very generally in the form of irregular fragments or masses, of all sizes, enclosed in the granite; while in other cases the granite forms irregular, branching dikes in the diorite. In fact, the granite, however massive it may be, is rarely entirely free from inclusions of diorite; and the diorite, even when farthest from a main body of granite, almost invariably exhibits a net-work of granite intrusions. In other words, the diorite has been very generally fissured, and in large part completely shattered, and then injected by the granite. Hence, although the two rocks are always perfectly distinct in their chronological relations, observing an invariable sequence, it is, for considerable areas, a hopeless task to trace or define the distribution of either separately from the other; and it is for this reason alone that they are not distinguished on the map. Any boundaries that might be drawn upon the map would have but very little significance, since in no case could they be either exclusive or inclusive. The granite very largely predominates; and the diorite, except as isolated inclusions in the granite, is quite restricted in its distribution. It has been observed chiefly in the ledges south of Cohasset Harbor, north and west of Little Harbor and along the shore between Little Harbor and Nantasket. The large ledge south of the Cove and west of the Gulf — Kent Rocks — is mainly granite, but encloses considerable diorite, while the pointed, rocky hill immediately east of the Gulf — Government

Rocks — is all granite, coarse and pinkish. In the large ledgy tract nearly half a square mile in extent between the Gulf and the Scituate shore, diorite appears to be the prevailing rock; but the granite is always close at hand and forms some large masses. The ledges along the Scituate shore, east of Cohasset Harbor and the Glades, and advancing from the south, are, except for an occasional inclusion of diorite, wholly composed of a beautiful, coarsely but uniformly crystalline and massive pinkish granite, which also forms the adjacent islands, from Barr's Rocks to the Osher Rocks. On reaching the prominent point a short distance north of the Osher Rocks, however, we pass abruptly from the granite to diorite with only occasional irregular dikes of granite breaking through it. The diorite forms the north shore of this point; but, crossing a short shingle beach, we find that the east shore of Strawberry Point is chiefly coarse granite; while across the north side there is much diorite alternating with the granite. It is partly in solid, unbroken masses, more commonly veined with granite, and to a considerable extent completely morcellated, yielding a very coarse breccia in which the diorite forms the fragments and the granite the cement. Gull Island presents at low tide a broad flat surface of diorite irregularly veined with granite; but Sheppard's Ledge and the ledges southwest of Gull Island are granite with little or no diorite. These characteristic relations of the two rocks are frequently repeated on the many other ledges and islets between Cohasset Harbor and Minot's Light, although the granite usually predominates. Along the north side of Cohasset Harbor, between the railroad and White Head, the ledges, so far as observed, are nearly all granite; and following the shore northward from White Head, around Sandy Cove, to the mouth of Little Harbor, the rock is all the most typical, coarsely crystalline, light gray granite, weathering pink or reddish, very massive in structure and with only very rarely a small inclusion of diorite. North of the narrow mouth of Little Harbor, on Beach Island, the granite continues, unchanged, to a point between 200 and 300 feet south of the artificial harbor on the

headland opposite Brush Island. Here we pass very abruptly from the coarse, massive granite to the mixed granite and diorite, for the first hundred feet or so a very confused mixture, in which the diorite seems to predominate; but west of that, along the entire stretch of shore, as far as Green Hill and Nantasket, the granite is the prevailing rock, with frequent inclusions of diorite. This is, structurally, an extremely interesting section, and it will be described more fully a little farther on. The essentially patchy distribution of the diorite in the granite makes the tracing of this rock in the weathered and lichen-covered inland ledges rather unsatisfactory, not to say unprofitable, and only enough work has been done in this direction to show that what we can see so clearly along the shore is really characteristic of the whole town. Thus it must be evident to any one observing the ledges along the west side of Little Harbor and on Forest Avenue that the mixed granite and diorite extends inland a considerable distance; while in other parts of the town it is equally clear that coarse and massive granite covers large areas.

The diorite is always dark-colored and holocrystalline, but usually rather fine-grained, varying in texture from compact or aphanitic to distinctly but not coarsely crystalline, *i. e.*, the diorite is rarely coarse in the sense that the granite often is. On the other hand, it rarely resembles diabase, except in the most compact forms, the normal difference in crystalline structure or habit being readily recognized in the macrocrystalline diorite. Under the microscope it is usually seen to be composed chiefly of plagioclase and hornblende. The feldspar is commonly rather opaque; but the hornblende is, in many cases, beautifully clear and dichroic, although usually bordered by secondary biotite, chlorite, etc.; while in the more compact and highly altered diorite the hornblendic element is very largely reduced to hydrous silicates, which give the rock a dark greenish color. Among the secondary minerals occurring in veinlets and irregular segregations epidote is most prominent, but it is frequently accompanied by chlorite and quartz. The black oxides of iron (magnetite and menaccanite) are usually present but rarely

abundant, and the rock also often contains a small amount of original quartz. The quartz diorite is especially interesting as indicating a gradual passage to the more basic granites.

The diorite is undoubtedly a plutonic rock; and it is sufficiently varied in character to suggest that it is possibly not all of the same age; but no facts have been observed which point to a definite conclusion, and all that can be regarded as well determined is that its relations to the granite are always essentially the same.

The granite, on the other hand, belongs very clearly to two, and probably three, more or less distinct periods of igneous activity, or successive phases of the same period. First in order of time comes the granite which is most intimately associated with the diorite. This is very abundant, and partakes of the character of the diorite. It is on the average only a little more coarsely crystalline than the diorite; and usually contains sufficient hornblende or black mica to make it quite dark colored for a granite. The quartz is often deficient, and the feldspar is partly plagioclase, so that it would be easy to mistake a portion of the rock for either diorite or syenite. The hornblende shows, perhaps, even more alteration than in the diorite, being very largely replaced by chlorite. Next in order comes the light gray and pinkish granite, which is usually coarsely crystalline and massive and is as a rule comparatively free from inclusions of diorite. This rock is rich in acid feldspar and quartz; but the hornblendic element is usually quite scantily developed; and black mica (biotite) often partially, sometimes wholly, replaces the hornblende, while both of these accessories are, as a rule, largely altered to chlorite or other hydrous species. It can be seen breaking through the first granite and the diorite at many points along the shore, especially between Little Harbor and Nantasket; and some of the smaller dikes of this granite are quite fine grained and not easily distinguished from the third type. This coarse acid granite is the only rock in this district of any particular economic interest; and it has been quarried only to a very limited extent. There is one small quarry on the

Scituate shore, near the Osher Rocks, and another on the Cohasset shore, north of Sandy Cove; but inland nothing deserving the name of a quarry has been observed. The third granite, in chronological sequence, forms small and irregular dikes from a fraction of an inch to several feet in width cutting all the older rocks, but occurring chiefly in the coarse, typical granite (No. 2), from which it appears to differ in composition only in containing less hornblende or mica. These dikes are always fine-grained, varying from a finely crystalline gray or pinkish granite or micro-granite to a true felsite.

The micro-granite passes into an acid felsite of the same chemical composition. But while the micro-granite is common, forming hundreds of small dikes, true felsite, which does not reveal a holocrystalline ground-mass under the microscope, is rather rare. The largest mass which has been observed is at the northeast corner of the large ledge of granite on the south shore of Lyford's Liking, south of Round Hill. This is a brown, thoroughly compact or felsitic, structureless rock; and forms a mass several yards across, just at the water's edge. The contacts with the granite are not clearly exposed; but it is evidently a dike in the granite. Small dikes of a true quartz-porphyry have also been observed on the Jerusalem Road, east of Green Hill. The great abundance of pebbles of felsite in the Nantasket conglomerates indicates that this rock was formerly much more extensively developed in this district. It probably occurred chiefly in the form of broad surface flows, such as still exist in other parts of the Boston Basin; and the dikes of both felsite and micro-granite probably date from these volcanic eruptions, being branches from the main fissures or necks through which the felsite reached the surface.

Although these three types of granite clearly reveal the chronological succession described above, it can not be shown that they are widely separated in time or belong to entirely distinct periods of igneous activity; and it is especially obvious that the micro-granite and felsite, although cutting the coarse

granite, should, on account of their resemblance to it in composition, be regarded as, in a general view, essentially synchronous.

This coast abounds in instructive exposures of the granitic rocks, but the nearly continuous belt of wave-washed ledges along the Jerusalem Road between Nantasket and Beach Island is particularly worthy of thorough study, illustrating, as it does, the relations of all the rocks and presenting some features which are not clearly exposed elsewhere. On the south side of Beach Island, as already noted, there is a fine development of the coarsely crystalline, massive granite; but from the junction of this with the mixed granite and diorite just south of the artificial harbor to Nantasket the finer-grained, dark-colored, older granite is the principal, and for a considerable portion of the distance, excepting the dikes, almost the only, rock. This older granite is characterized throughout the entire section by a remarkable gneissoid structure due to the flowing of the material while in a viscous condition. At many points this flow-structure is so perfectly developed that the rock presents a distinctly gneissic character even in small hand-specimens; and where the fluidal lines are least obvious, they are still traceable on the broad, clean surfaces of the ledges. The trend of the flow-structure or pseudo-stratification varies somewhat. It is about N.E.–S.W. on Beach Island; while farther west it ranges usually between N.–S. and N.W.–S.E., but becomes N. 60° W. as we approach the beach leading to Green Hill. The dip is usually nearly vertical, although sometimes as low as 60° or less.

This gneissoid granite encloses at most points numerous fragments of diorite of varying lithological character. These exhibit a great range in size; and they are usually more or less elongated in form, being often distinctly lenticular and indicating in their smooth and somewhat indefinite outlines a partial fusion of the diorite in the melted granite. The elongated fragments coincide in direction with the flow-structure of the granite, and this structure is always most perfect where the diorite is most abundant. The form of the diorite fragments means, probably, that the

diorite also possessed a gneissic structure of some sort before the eruption of the granite; in fact this can frequently be observed in the more lenticular masses of diorite. The diorite, then, has been injected by the granite chiefly along its own original structure-planes; and the flow-structure of the granite is probably due largely to its having come up between these parallel walls of diorite.

Breaking through this gneissoid granite and the enclosed diorite at irregular intervals are many small and some large masses of the coarse, light-colored granite. These usually conform in direction, at least approximately, with the flow-structure of the older granite, and exhibit in this direction a similar but, as a rule, less distinct flow-structure. We thus not only have a somewhat gneissoid diorite of probable igneous origin broken through very profusely by, and enclosed in, a highly perfect gneissoid granite — a true eruptive rock which, but for its relations to the diorite, might readily be classed as of sedimentary origin, a true gneiss; but both of these terranes are traversed again and again in a way possible only to an igneous rock, by a second and more acid pseudo-gneiss. Again, all the preceding rocks are injected by occasional small and irregular dikes of microgranite and felsite, which, for the most part, are devoid of gneissic structure. And, finally, this entire sequence of granitic eruptions is divided by a well-defined series of porphyrite dikes and no fewer than three distinct systems of diabase dikes; all of which will be described in connection with the dikes of Nantasket.

This shore undoubtedly presents the best general section of the plutonic rocks of the Boston Basin. Certainly at no other point do we find plutonic masses of so many different ages so clearly exposed in their normal relations; and in this connection it should be noted that the passage (in natural sequence) from the diorite through the more basic to the more acid granite affords some indication that the diorite is not widely separated in time from the granites, the entire series constituting but one complete igneous cycle.

THE ROCKS OF NANTASKET.

GENERAL RELATIONS AND ORIGIN.

Although the surface exposures of the rocks of the Nantasket area are completely isolated by drift deposits and the sea, these strata are probably continuous to the north and west with the great body of sediments occupying the Boston Basin. And it is certain, as will appear later, that they are terminated on the south by profound dislocations; so that the sharply defined boundary between the Nantasket sediments and the broad area of granite can not be regarded as marking the true original border or maximum extension of the Boston Basin in this direction. On the contrary, the facts point very plainly to the conclusion that the basin rocks formerly extended a considerable but undetermined distance beyond this line; being here, however, on the upthrow side of the great faults, they were lifted above the present plane of erosion. We may, nevertheless, entertain the hope that future investigation will reveal upon the granitic plateau outlying remnants of the sedimentary series, and thus indicate more exactly the original limits of the basin.

The Nantasket rocks, above the fundamental granite, and omitting the dikes, consist chiefly of the conglomerate (Roxbury pudding stone) and the interbedded lavas and tuffs. The incompleteness of the Nantasket section is plainly shown in the entire absence of the great slate series, which elsewhere in the Boston Basin overlies the conglomerate; and it is probable, as will appear when the facts are presented, that the upper members of the conglomerate series are also wanting. The student will, however, find compensation for these deficiencies in the magnificent development of the basal beds of the conglomerate. At no other point are the floor of the Boston Basin and the strata rest-

ing directly upon it so clearly and instructively exposed. On the other hand, the eccentric position of Nantasket with reference to the basin as a whole renders it a natural if not a necessary inference that the beds which are here seen to repose upon the granite are not the lowest or oldest sediments of this series; but these must be sought farther north, along the axis of the basin, which, according to the view of a progressive subsidence during the deposition of the conglomerate and slate, must be the deepest and oldest part of the trough.

Throughout the Nantasket area the true conglomerate, as distinguished from the tuff, is largely composed of granitic detritus; but this material is especially prominent where the lower beds of conglomerate lie immediately upon the granite. The volcanic rocks intercalated in the sedimentary series include three principal kinds: melaphyr, melaphyr-tuff and porphyrite; and, as will appear in the detailed descriptions, the evidence for the contemporaneous origin of these igneous sheets is well nigh perfect at every point. It has been found impracticable, in the main, to determine satisfactorily the positions of the volcanic vents. It appears probable, however, that the eruptions were chiefly submarine; while the tuffs would seem to indicate that the lavas issued to some extent from craters rather than fissures; and we may well suppose that these ancient igneous channels, of whatever form, are still buried beneath their own ejectamenta. It will be shown, however, that the source of the more acid lava, the porphyrite, is probably indicated in part at least by the dikes of porphyrite along the Cohasset shore; and of the oldest melaphyr by the great dike of melaphyr (2) in the western area.

Briefly stated, then, the history of the Nantasket strata is substantially as follows: The district now known as the Boston Basin, which had previously been a land surface, experienced a gradual but profound subsidence, during the progress of which the sea slowly encroached upon what is now the Nantasket area. The abundant detritus which must have resulted from the sub-aerial chemical decay of the granitic and other crystalline rocks of this region during long preceding ages — a thick sheet of seden-

tary soil such as may now be observed in low latitudes — was rapidly worked over by the advancing tide to form extensive beds of gravel and sand on the beaches and near the shore, while the clayey constituent of the soil was carried far out into the deeper waters of the bay.

Not long, apparently, after the formation of these strata began, and as a result, probably, of the same agency that gave rise to the subsidence, volcanic phenomena were instituted in different parts of the Boston Basin; and for a long time Massachusetts Bay must have borne some resemblance to the modern Bay of Naples. But since, as already stated, the eruptions were largely submarine, this region doubtless exhibited a still more perfect combination of aqueous and igneous activity. Sheets of basic and sub-acid lavas of greatly varying thickness and extent were poured out over the newly formed beds of gravel and sand and were in turn covered by these ever-growing deposits, the overlying gravel enclosing many fragments worn from the lava itself. The different flows of lava represented in the same vertical section are usually separated by considerable beds of conglomerate; but sometimes the eruptions succeeded each other so rapidly as to produce composite beds of lava, or lava and tuff, several hundred feet thick without any interlarded sediments. Some dikes of porphyrite and at least two of melaphyr probably date from this period and may, perhaps, be regarded as channels through which the lava reached the surface. But the great majority of the dikes traversing the conglomerate and melaphyr are diabase and appear to have been formed long subsequently, when, after the upper conglomerate and a great thickness of slate had been quietly deposited over this area, the strata were tilted up and extensively faulted. The geologic revolution marking the close of this period in the history of the Boston Basin was not attended by severe plication in the Nantasket area; but faulting is by far the more prominent structural feature. The subsequent history of this area, during all the long ages down to the glacial epoch, is recorded only in the quiet erosion which has swept away the great slate series and, at some points, the entire thickness of the conglomerate and interbedded lavas.

GENERAL STRUCTURE OF THE NANTASKET AREA.

The main structural features are so clearly expressed on the map that this topic may be treated very summarily. Nantasket is a monoclinal area; and, although it has been completely shattered by numerous faults and dikes, the strata exhibit only low and little variable dips, being almost unique in this respect among the sediments of the Boston Basin. Along the northern margin, from Atlantic Hill to Rocky Neck, the prevailing dip is south-southeast 10° to 20°. But southward, or toward the granite border, the dip usually diminishes, and becomes more easterly, the beds immediately adjoining the granite being often horizontal or having a slight inclination obliquely away from the granite. These gently inclined beds, together with the granite floor on which they rest, are broken by longitudinal and transverse faults into a series of blocks. A glance at the map, on which the faults are represented by broken black lines, shows that these blocks are extremely variable in form and size; and it is somewhat surprising that the unequal up and down movements or jostling of these numerous earth-blocks could take place without greater disturbance of their bedding-planes.

The principal longitudinal faults, such as those immediately bordering the granite and the profound fracture which skirts the southern shore of Nantasket Harbor, traversing the entire district from Strait's Pond to Weir River Bay, downthrow to the north; and the displacements are so great that, although the bedded rocks dip toward the granite, in receding from the granite northward we pass in general from older to newer strata. The continuity of the strata is interrupted so frequently and completely, both longitudinally and transversely, by the numerous faults; and the conglomerate is, in the main, so homogeneous and the tuff so local; that we are obliged to depend very largely upon the lithological characters of the interbedded lavas in correlating adjacent ledges as well as the more widely separated parts of the field. The sequence of the

bedded rocks of the entire area can not be read off directly from any more or less continuous or connected horizontal sections. But we find instead numerous isolated vertical sections, which can only be correlated, if at all, by a critical ledge-to-ledge study and comparison. The best results of such an investigation are presented in the subjoined general section of the Nantasket strata; from which it appears that above the granite floor there are no fewer than six beds of conglomerate, alternating with five sheets of melaphyr and tuff and one sheet of porphyrite.

Table of the Nantasket Strata.

Granite, bordering and underlying the bedded rocks.	
First Conglomerate, basal, resting on granite	25-50 feet.
Rocky Neck, Granite Plateau, Cliff Plateau, etc.	
First Melaphyr, compact and jaspery	25-40 feet.
Rocky Neck, East and West Porphyrite Hills and Cliff Plateau.	
Second Conglomerate, jaspery	25-50 feet.
Rocky Neck, East and West Porphyrite Hills, Great Hill, etc.	
Porphyrite	50-100 feet.
East and West Porphyrite Hills, Black Rock, etc.	
Third Conglomerate	50-100 feet.
Conglomerate Hill and Plateau, Folsom's Island, Round Hill and Green Hill.	
Second Melaphyr, green and amygdaloidal	20-30 feet.
Crescent Hill, Melaphyr Plateau, and South Shore.	
Fourth Conglomerate	20-30 feet.
Crescent Hill, Marsh Island, etc.	
Third Melaphyr, green and amygdaloidal	35-45 feet.
Rocky Neck, Melaphyr Peninsula and Plateau, Crescent Hill and Marsh Island.	
Fifth Conglomerate	25-30 feet.
Rocky Neck and Long Beach Rock.	
Fourth Melaphyr and Tuff, green, compact or brecciated .	300-450 feet.
Atlantic and Centre Hills, Gun Rock, Little Black Rock, etc.	
Sixth Conglomerate	10-15 feet.
Rocky Neck.	
Fifth Melaphyr, green and amygdaloidal	15-20 feet.
Rocky Neck.	
	600—960

The assigned thicknesses are in part actual measurements; but chiefly estimates and approximations. They are intended, also, to give some idea of the variations in thickness observed in tracing the individual beds from one part of the field to another.

While it must be admitted that the data upon which this table rests are in some respects much less conclusive and more ambiguous than could be desired, it may be fairly considered a conservative determination as regards the number of distinct terranes involved; since in all cases where the indications appeared to be evenly balanced that interpretation of the facts has been preferred which avoided multiplying the alternations of conglomerate and lava. It is quite possible, indeed, that in some instances what have been regarded as parts of one continuous sheet of lava are really entirely distinct and, perhaps, not even synchronous flows. This view would, however, seem to carry the further supposition that some of the flows failed to extend over the entire field. This is not, *a priori*, improbable; though few facts have been observed which seemed to demand this explanation. Some of the tuff beds are unquestionably very local, the underlying and overlying melaphyrs coming together abruptly at their margins; but, although carefully sought, no corresponding indications have anywhere been detected in the melaphyr, except in the case of the flow on Atlantic and Centre Hills which appears to be terminated on the west by the junction of the underlying and overlying tuffs. It is very clear, however, that, as already stated, the melaphyr flows are composite in some cases, several eruptions having followed each other in quick succession over the same area. This is conspicuously true of the fourth melaphyr, the great sheet forming Atlantic and Centre Hills, etc.

Although, as the map shows, few of the Nantasket faults can be classified as distinctly longitudinal or transverse, the greater number are either approximately east-west or north-south in direction. It is also noticeable that the blocks bounded by the principal faults are in several instances broken into quite narrow wedges by a series of parallel east-west faults.

The arrows pointing away from the fault lines on the map indicate the direction of the downthrow in each case; and the accompanying figures, when present, express the amount of the displacement in feet wherever it could be even approximately determined.

The map also brings out very clearly the principal facts concerning the dikes of Nantasket — their sizes, trends, distribution and correlation in different outcrops. Mr. Merrill has shown that they consist almost exclusively of diabase, and are all highly altered; although they exhibit some notable differences in texture and degrees of alteration. The dikes are numbered on the special map, and the numbers are repeated for each important outcrop, so as to express more clearly their individual continuity. The most of the dikes are readily arranged by their trends in three distinct systems. The dominant trend is manifestly approximately east-west. But these are seen on closer inspection to embrace two systems, diverging 20° to 30°. The normal trend of the first or oldest system is N. 75° to 80° E., and of the second S. 75° to 80° E. Their relative ages are indicated by a slight difference in texture and especially by a very clear intersection on the shore east of Gun Rock and several intersections on East Porphyrite Hill. The third system trends due north-south and is the newest of all, as shown by two intersections of dikes of the second system: Dike 62 cuts dikes 13, 14 and 15 of the second system in Green Hill Ledge very clearly indeed; and the composite dike (66) in the gorge between East Porphyrite Hill and Cliff Plateau certainly cuts 31 of the second system which in turn cuts 22 and 24 of the first system on East Porphyrite Hill. Notwithstanding the regularity of their forms and trends, the dikes, with the partial exception of the newest system, exhibit a remarkable independence of the best developed systems of joint-planes. This is especially noticeable along the northern bases of Atlantic and Centre Hills, indicating that the older dikes, at least, probably antedate the joint-structure of the rocks to some extent. A further inspection of the map will show, however, that not only

do some of the dikes coincide in position, but they all coincide in direction, with the fault-lines of the district. This general coincidence in trend of the faults and dikes is a very significant fact, indicating that the dikes date from the period of general disturbance, when the rocks were tilted and faulted. The map also brings out the fact that the east-west dikes occur in three distinct zones or belts, marking the three principal dislocations of the Nantasket area.

LITHOLOGY.

To avoid unnecessary repetition in the detailed descriptions of the Nantasket ledges we may advantageously notice in advance the general lithological characters of the principal types of rocks. These fall naturally into three classes, as follows :—

(1). Sedimentary rocks, consisting chiefly of the conglomerates.

(2). The older eruptive rocks, embracing the diorites, granites and felsites.

(3). The newer eruptive rocks, including both dikes and lava-flows.

The third division is by far the most important; and it is a matter for sincere congratulation that it has been worked up by a competent specialist.

The Sedimentary Rocks.

The Nantasket conglomerate is, with unimportant exceptions, chiefly composed of well rounded or water worn fragments of granite, felsite, melaphyr and porphyrite. On account of the predominance of the granite and felsite débris, the conglomerate is, in general, light-colored, pinkish or reddish. It has in

the main the medium texture of the Roxbury puddingstone, the pebbles not exceeding four inches in diameter; but at some points, such as Great Hill, Green Hill Ledge and the small area north of Crescent Hill, they are in part much larger, one to two feet. The larger pebbles are chiefly granite and melaphyr, the felsite having been always, as now, too brittle and too finely jointed to form many large pebbles. The conglomerate is usually a typical puddingstone, presenting distinctly the character of a breccia only where it immediately overlies the granite, and is largely composed of local granitic débris.

It is very noteworthy that the quartzite pebbles, which are such a prominent feature of the conglomerate in most parts of the Boston Basin, are almost entirely wanting in the Nantasket ledges; indicating that formerly, as at the present time, the ancient quartzites had but a slight development on this side of the basin. The same reasoning will not, however, explain the general absence of pebbles of diorite in the conglomerate. Next to granite, diorite is by far the most abundant of the older rocks bordering the Boston Basin, covering an aggregate area of at least one hundred square miles within ten miles of the present margin of the basin. Since the diorite is everywhere intersected by, and therefore older than, the granites, it is unquestionably also older than the conglomerate; and we are obliged to suppose that, like the other of our older rocks, it was probably abundantly exposed over the surface of this region during the formation of the conglomerate. A few pebbles in the conglomerate, in different parts of the basin, may be doubtfully referred to the diorite; but, generally speaking, this rock has contributed little or nothing to the composition of the conglomerate. Bowlders and finer débris of the diorite are extremely abundant in the glacial drift of this section; but it is noticeable that the smaller masses, especially, are usually more or less decomposed, showing much more alteration than similar fragments of granite or felsite. If, therefore, as already suggested, we may follow Mr. Bouvé[1] in attributing the formation of the early sediments of this region to the working over by the sea of

[1] Proc. B. S. N. H., xxiii., 29-36.

a thick sheet of sedentary soil or chemical detritus, it is obvious that the more basic rocks, like diorite and diabase, must have been more deeply and thoroughly decayed than the more acid rocks, like granite and felsite, the latter being intermediate in this respect between the former and the purely silicious rocks—the quartzites. The débris of the diorite is, therefore, to be sought in the slate rather than in the conglomerate; and we must recognize the principle that the occurrence of older rocks in the conglomerate is not in the order of their abundance so much as of their chemical stability.

Limited layers of finer sediment—grit and sandstone—by reference to which the dip and strike may be determined, occur rather sparingly in most of the Nantasket ledges, as in Long Beach Rock, Green Hill Ledge and Great Hill; although they are practically wanting in several of the largest masses, including Conglomerate Plateau and Conglomerate Hill. The conglomerate is throughout very firm and thoroughly consolidated, breaking, usually, without reference to the contours of the almost adamantine pebbles. In fact, the paste, including the intercalated sandstone layers, is often so intensely hard as to suggest that the volcanic heat of the interbedded lavas has been an important agent in lithifying these ancient gravels. This is undoubtedly a true cause, but still it does not afford an entirely adequate explanation of the phenomena, since the conglomerate beds are usually well indurated through their entire thickness, even the lower layers of gravel, which were deposited upon a cold and eroded surface of lava, being sensibly as hard in most cases as the upper layers, which were covered by a stream of incandescent lava. There are, on the other hand, many facts which indicate that the intense lithification is largely due to the deposition of secondary silica over and between the grains composing the paste, thus virtually changing the arenaceous matrix of the pebbles to quartzite. This interstitial silica is especially obvious where it takes the form of distinct segregations of red jasper, as in the western part of Nantasket and on Rocky Neck.

Its source is undoubtedly to be found chiefly in the alteration of these basic lavas; and it occurs even more abundantly in the melaphyr itself than in the conglomerate, in the form of irregular segregations and veins of jasper, chalcedony and vitreous quartz.

The Older Eruptive or Granitic Rocks.

Both the diorite and the older, dark colored granite of the Cohasset shore are practically wanting in the Nantasket area; the granitic rocks being limited to the coarsely crystalline, acid type, excepting a few small, irregular and ill-defined dikes of finely crystalline granite (micro-granite) and felsite. The extraordinary abundance of pebbles of quartz-porphyry and other varieties of felsite in the conglomerate is a plain indication that these rocks were far more extensively developed over the granitic area in early times than now, forming, probably, surface flows as well as dikes. The coarsely crystalline, acid granite of Nantasket is essentially similar to that of Cohasset and the South Shore generally; and little need be added to the statements of the preceding pages. Over Granite Plateau and Granite Point and on Rocky Neck the relations of the basal conglomerate to the granite are very intimate and intricate; but absolutely no facts have been observed which indicate that the granite is intrusive in the conglomerate, or that any of the granitic rocks of the Nantasket region are more recent than the sedimentary rocks. On the contrary, the relations of the two series, as will appear later, are, at every point, consistent with the view that the conglomerate was deposited over an uneven, fissured surface of the granite, such as that rock presents to-day at many points.

The Newer Eruptive Rocks.

BY GEORGE P. MERRILL.

The more recent eruptive rocks of Nantasket, including all those of later date than the diorite, granite and felsite, occur in the form of (1) lava-flows and (2) dikes. The lava-flows include both melaphyrs and porphyrites and these volcanic types are also found among the dikes, although the latter consist chiefly of diabase. The melaphyrs and diabases have, in many cases, undergone such complete alteration that their correct identification is attended with the greatest difficulty. Indeed, the slide often shows not a single recognizable original constituent; but consists wholly of a compact aggregate of secondary minerals, among which are epidote, quartz, kaolin, and sundry chloritic and ferruginous products for which there are, perhaps, no better names than the terms *viridite* and *opacite*, already in general use.

Perfectly satisfactory results from such materials could be obtained only by prolonged and careful microscopic examinations and chemical tests, accompanied by study in the field, where the rocks could be observed in all their varying aspects and in varying stages of alteration. Such study I have naturally been unable to give them, and my main effort has been to so identify the rocks and note their essential differences, if any, as to aid Professor Crosby in his difficult task of ascertaining their field relations.

The Lava-flows or Volcanic Rocks.

The effusive rocks or true lavas of Nantasket embrace, as stated, two principal types—melaphyr and porphyrite. The melaphyr is the predominant type and forms several distinct flows or sheets, of varying lithological character; while the porphyrite, so far as known, may all be referred to one widely extended sheet.

Melaphyr.

The melaphyrs throughout the Nantasket area differ from the diabases in being of a finer grain, in that their feldspars are less decomposed, and in never, so far as observed, containing a recognizable unaltered trace of either augite or olivine; also in being, as a rule, more or less amygdaloidal. They also carry a considerable proportion of amorphous base. These characteristics are alone sufficient in every case examined to distingtuish the so-called melaphyrs from the diabases (or the surface flows from the later dike rocks). The melaphyrs also carry a larger proportion of secondary epidote, and less of the viridite, these two substances occupying the space of the decomposed feldspars and augites and filling the amygdaloidal cavities. The feldspars have the appearance described by Benton[1]; and, although still showing twinning striæ, are more or less kaolinized or show traces of the viriditic and epidotic alteration so common in the dike rocks. The black material of the ground-mass is in part magnetite, as shown by its bluish reflections and by its being strongly attracted by the magnet; but it is often accompanied by blood red scales of hematite.

The amygdules in these rocks are in part true steam-holes or vesicles, as shown by their regular oval form, sharply defined walls, and the arrangement of the enclosed and adjacent minerals. In other cases, however, they are merely cavities left by the decomposition of some constituent of the rock, and are irregular in outline, poorly defined and show frequently the remains of some less easily decomposed mineral, as a feldspar, projecting from the cavity wall inward. These *pseudo*-amygdules, like the true amygdules, are filled with a variety of secondary minerals, as feldspar, quartz, epidote and chlorite, often without definite order, or again showing a quite regular concentric arrangement. I have not, however, been able to find the marked regularity in the arrangement of these minerals in the pseudo-amygdules that I was led to expect from a peru-

[1] Proc. B. S. N. H., Vol. xx., page 416.

sal of Mr. Benton's paper. The chlorite of the amygdules is quite different from the so-called viridite of the diabases. With a low power and by ordinary light it appears like a continuous sheet of a light green micaceous mineral viewed perpendicularly to its cleavage; but with a power of 400 or 500 diameters, it is seen to be a compact mass of minute scales which is almost black between crossed nicols, but which polarizes faintly as the stage is revolved and shows at the same time that the individual foliae have a fan-shaped arrangement. It very likely represents the final stage of the viriditic alteration, and is presumably the same as the dark green compact chlorite which occurs in masses of some size in the amygdules of the melaphyr at Brighton.

Numerous other minerals of secondary origin are found in the cavities and crevices of the melaphyr; but as they occur only in minute quantities in the material at hand and usually without well defined crystallographic outlines, their correct determination is a matter of great difficulty, and in some cases would be impossible. For this reason and because they do not appear to have any important bearing upon the problems under consideration I have omitted mention of them in my descriptions.

Fourth Melaphyr, Coastal Area. — This is a fine grained greenish rock, with few macroscopic constituents. True amygdules are rarely abundant in the melaphyr of this area, but it is very commonly distinctly brecciated, considerable masses having a highly fragmental aspect. Under the microscope it is found to consist of the usual lath-shaped plagioclases with step-like ends imbedded in a grayish amorphous ground-mass and showing a marked fluidal arrangement. Much secondary epidote is present, occurring in scattered grains, in strings or veins and in aggregates filling the numerous small cavities resulting from the decomposition of some of the original constituents of the rocks. There is also present a considerable amount of viridite, which results from the alteration of the augites, and is also derived in part from the ground-mass. This at times occupies the entire interspaces of the feldspars, and, act-

ing but faintly on polarized light, gives them the appearance of being imbedded in a light greenish glass.

In the limited bed on the north side of Atlantic and Centre Hills, bomb-like masses of melaphyr are highly amygdaloidal, the amygdules varying from 1 to 5 mm. in diameter. These I regard as true amygdules. They are filled mainly with quartz and chlorite, though often a little epidote is present. In such cases the quartz occupies the outer zone with the chlorite and epidote interiorly. The ground-mass of this rock is an extremely dense, dark brownish gray, amorphous material bearing minute feldspar microlites.

The pseudo-amygdules of this melaphyr are commonly much elongated, and contain epidote and chlorite with more or less quartz. The epidote occurs as minute crystals, a single row of which often forms a border around the wall of the cavity; while the entire central portion is occupied by the very compact, light green chlorite noted above. Outside of the amygdules or segregations of both kinds, scattered through the entire mass of the rock, are the common decomposition products, ferrite, opacite, viridite and kaolin.

A typical sample of melaphyr from this area, but bearing some secondary quartz, which could not be avoided, yielded 50.47 per cent. of silica.

Second and Third Melaphyrs, Central Area.—The melaphyrs of this area are usually of a deep greenish color and often highly amygdaloidal; but they vary greatly in both color and texture. A common type is a dark purplish gray rock, which is also often profusely amygdaloidal. Under the microscope its color is seen to be due to the large amount of opacite and magnetite in the ground-mass. Secondary epidote is abundant in comparatively large grains, which are often surrounded by a dense black border of opacite. The amygdules are filled with quartz, epidote and feldspar. The quartz and epidote prevail and occur in the form of an extremely fine grained and compact aggregate having a specific gravity of about 2.9. The iron

oxides, which are much decomposed, are in part titaniferous, as shown by their peculiar club-shaped forms so characteristic of menaccanite. Moreover, the pulverized rock gives a distinct reaction for titanium, after prolonged digestion with hydrochloric acid. The green melaphyr differs mainly in carrying a larger proportion of epidote and in the feldspars having undergone the viriditic alteration. The amygdules of the rock show first a zone of epidote, and interiorly quartz, feldspar and chlorite. A typical sample of the melaphyr from this area, non-amygdaloidal and carrying no free quartz, yielded on analysis 41.89 per cent. of silica.

First Melaphyr, Western Area.—The structural features of this rock are greatly obscured by decomposition, but after the examination of several sections I am disposed to place it with the melaphyrs. The microscope shows it to consist of a large number of greatly decomposed porphyritic plagioclases imbedded in a groundmass so filled with secondary decomposition products that its original character is wholly obscured. The dull green macroscopic areas are epidote resulting from the feldspathic decomposition. The original iron-magnesian constituents have quite disappeared, even their outlines being no longer recognizable. I assign the rock to the melaphyrs with considerable hesitation. Chemical analysis shows its basic character, three samples from different localities affording the following percentages of silica: 47.29, 47.97 and 51.05; the latter, at least, probably including some free secondary quartz.

Porphyrite.

The rock which I here have called porphyrite differs from the melaphyrs in showing under the microscope a larger proportion of irresolvable ground-mass, in being of a more pronounced porphyritic structure and in never so far as observed being truly amygdaloidal. They are also more compact and fresh appearing and show in none of the sections examined

traces of augite, olivine or other original iron-magnesian silicates.

Western Area.—The porphyrite of this area varies from light greenish to dull red and purplish in color and is well described by the term *felsitic*. So far as observed none of its mineral constituents are of such dimensions as to be recognizable by the unaided eye, nor is it at all amygdaloidal, a feature so pronounced in the melaphyrs. The purple variety, in the thin section, shows a densely microlitic base, with much opacite, carrying numerous porphyritic feldspars, which are mostly, if not all, triclinic. A few of the feldspars show no twinning striæ; but I cannot obtain such measurements as would prove these to be certainly monoclinic.

One of the sections examined shows a single corroded bleb of original quartz, carrying fluidal cavities and moving bubbles. Large dusky apatites are not rare. In the greenish variety there is also present a little viridite from the feldspars, and a few granules of secondary epidote. The porphyrite presents, usually, a well-marked fluidal structure. Subjected to chemical analysis, the green variety yielded 58.02 per cent. of silica, and had a specific gravity of 2.73. The red variety is more felsitic and also more decomposed. Two samples, light red, and dark red in color, yielded silica as follows: light, 56.66 per cent.; dark, 56.25 per cent.

Black Rock.—Some of the black rock porphyrite more resembles the melaphyrs in external appearance than does that of the western area. Macroscopically it is a very compact and hard, greenish gray to dark purplish and nearly black rock, bearing small whitish feldspars, and secondary epidote in crystals and granular aggregates of sufficient size to be distinguishable by the naked eye.

Thin sections, under the microscope, show it to consist of a dense ground-mass of needle-like and short, stout feldspar microlites, interspersed with numerous brilliantly polarizing epidote

granules, and with little if any truly amorphous base. Imbedded in this feldspathic ground-mass are numerous large, clear and often greatly corroded plagioclases. A few small apatites are present. The section shows a well-marked flow-structure. Chemical analysis yielded 58.25 per cent. of silica; and an average of four determinations gave a specific gravity of 2.78.

The Dikes or Intrusive Rocks.

The dikes, as has been noted by Professor Crosby, are all of normal form — sharply defined, wall-like masses making high angles with the horizon and invariably cutting across the stratified rocks; no intrusive beds or sheets having been observed in the Nantasket district, owing, probably, to the absence of thin bedded or slaty sediments. As previously stated, the dikes consist mainly of diabase; but they also include an important series of porphyrite dikes and at least one large dike of melaphyr. The dikes of melaphyr and porphyrite are believed by Professor Crosby to be contemporaneous with the surface flows of those rocks; while he finds that the numerous diabase dikes are certainly newer in most, and probably in all, cases than the melaphyr and porphyrite. Hence, following the chronological order, we begin with the last named rocks.

The Melaphyr Dikes.

The dike of melaphyr (1) on the north side of Centre Hill is so evidently identical with the melaphyr which it intersects that it was not examined microscopically. The large dike (2) in the western area, which Professor Crosby regards as contemporaneous with the first flow of melaphyr, is, like that flow, of doubtful character. Macroscopically, it bears a marked resemblance to this flow, and is contrasted in appearance with all the diabase dikes of the district. Under the microscope it is seen to be a fresher and more crystalline rock than the melaphyr, showing in the section a ground-mass of feldspar microlites and

granules injected with epidote and the usual ferruginous decomposition products. In this ground-mass are numerous phenocrysts of feldspar and an occasional nearly colorless augite. There are numerous granular areas of secondary epidote; but no trace of olivine or its decomposition products; and I am inclined to doubt its presence as an original constituent. Recognizing the uncertainty attending the determination of such rocks from a single section, I can only say that I am inclined to believe the rock more nearly related to the augite-porphyrites or olivine-free diabases than to the melaphyrs. It is classed here with the melaphyrs simply because the true nature of the rock is not yet free from doubt, and that arrangement best accords with its field relations as worked out by Professor Crosby. The analysis of a single specimen gave 54.47 per cent. of silica.

The Porphyrite Dikes.

The porphyrite dikes, so far as observed, are, lithologically, essentially similar to the great flow of porphyrite on Black Rock, rendering a detailed description unnecessary.

The Diabase Dikes.

These dikes are, as a rule, exceedingly compact, tough and hard, of a dark gray, nearly black or more frequently greenish color, and carry few if any original macroscopic constituents, although pyrite and secondary epidote are often developed in granules and aggregates of sufficient size to be detected by the unaided eye. To this secondary epidote and the abundant viridite is due in all cases the green color of the rocks.

I find nothing whatever in the slides, with possibly a single exception, to indicate that the different dikes belong to distinct periods of eruption. Slides from dikes which plainly belong to the same system often show all the variations in texture, structure and stages of decomposition to be observed in those which

from their position belong unmistakably to distinct systems. In grouping the rocks as below I have, therefore, but followed the notes of Professor Crosby.

First Series.

Dike 3. —Rock finely porphyritic with greenish feldspars; macroscopic pyrite; color greenish. This is a very typical diabase, with irregular and sharply wedge-shaped augites, lath-shaped plagioclases and numerous grains of iron oxide. The augites are undergoing a chloritic alteration; and the feldspars are so badly kaolinized that the twinning striæ are completely obscured. The iron oxides are in part magnetite and in part show the whitish alteration characteristic of menaccanite. Pyrite occurs in brassy yellow irregular clumps. Small, irregular, brown and strongly dichroic scales attached to the altered augites are evidently secondary hornblende. The porphyritic feldspars are so thoroughly kaolinized that nothing whatever can be learned of their original nature. Scattering grains of epidote, kaolin, opacite and viridite complete the list of recognizable constituents.

Dike 5.—Very fine grained and compact; macroscopic pyrite; color greenish. This presents no distinctions in any way essential. Both augites and feldspars are more decomposed; and there is a corresponding increase in the proportions of epidote, viridite, calcite, etc. A few small apatites appear in this slide.

Dike 22.—Medium fine in texture but distinctly crystalline, and color greenish. This differs from the preceding only in being slightly coarser in texture. The iron oxides, judged by their irregular forms and whitish decomposition products are largely titaniferous.

Dike 25.—Very fine-grained and compact; a few greenish feldspars porphyritically developed; and color greenish. The

augite is in most cases completely altered; and there is much viridite, epidote and iron oxide. This rock is undoubtedly a diabase, although I am unable to find a particle of recognizable augite or even hornblende, the viriditic alteration being complete in all the sections examined.

The viridite is very abundant and is considered of undoubted augitic derivation, from its sharp straight and very angular outlines, which are so characteristic of the augites in this class of rocks. Minute epidotes are in some cases very abundant and impart to the rock a yellowish green stain. The section is traversed by veins of secondary quartz.

Dike 37.—Very fine grained and compact; macroscopic pyrite; color, greenish. This is of finer grain than any of the preceding and so highly altered that none of its original constituents are now recognizable, excepting by pseudomorphs. The section shows only a fine, compact, fibrous or scaly aggregate of viridite, opacite, epidote, calcite and kaolin, with numerous grains of iron oxide. Although so highly altered, I have no hesitancy in referring this rock to the diabase group.

Second Series.

Dike 12.—Very fine grained and compact; no macroscopic constituents; color, dark greenish gray. Under the microscope it is seen to be highly altered, but with portions of augite still fresh and showing pleochroism. Iron oxide very greatly altered to a grayish amorphous product. Other alteration products as in preceding sections.

Dike 11.—Differs from 12 only in being of slightly coarser texture and in having suffered more from alteration; augites completely changed.

Dike 10.—Fine grained and compact; porphyritic with small greenish feldspars. Plainly a diabase, although the feldspars

are so muddied by decomposition products as to be scarcely recognizable. A few augite particles are still unchanged. No essential differences.

Dike 9.—Like 10, but a trifle coarser in texture. The hand specimen shows small black segregations of what is apparently hornblende; but these do not appear in the section.

Dike 8.—Very compact, with no macroscopic constituents; color, dark gray, nearly black. The sample was taken from the edge of the dike at the contact with melaphyr. It offers no characters worthy of note to distinguish it from 9.

Dike 7.—Coarse and distinctly crystalline; color, greenish. This is one of the coarsest rocks of the series. Under the microscope it shows large plates of reddish brown augites, often enclosing the lath-shaped plagioclases and producing the typical ophitic structure. The feldspars here are sufficiently fresh to show twinning striæ. Iron oxide is very abundant, in large grains, with much pyrite and some apatite. The section shows to excellent advantage the various stages of augitic alteration into viridite. The rock resembles 22 more closely than any of the preceding.

Dike 26.—Very fine, compact and homogeneous. Color, dark gray, somewhat greenish. This rock is greatly altered; being essentially an aggregate of viridite scales, and fibres and granules of iron oxide, interspersed with epidote. A few cavities or pseudo-amygdules occur, the cavity wall being lined with viridite, while the central portion is occupied by calcite. The feldspars are very obscure; and the iron oxide in part titaniferous.

Dike 29.—Texture of medium fineness, with large segregations of black hornblende. Color, uneven, black, greenish and yellowish green; the last tint being due to epidote veins. The augite is greatly altered; and there is much viridite and epidote, the latter in scattered granules and veins. The feldspars are ob-

scure; and quite large grains of iron oxide and pyrite occur. The segregation patches already alluded to are found, under the microscope, to consist largely of deep brown, strongly dichroic hornblende, in compact and well-defined crystals; sometimes perfectly fresh or again somewhat altered into the inevitable viridite. I am not able from the sections prepared of this rock to state whether this hornblende is original or a product of paramorphic alteration from the augite.

Dike 31.—This is of medium fineness, with macroscopic pyrite and segregations of black hornblende. The color is greenish, the rock being blotched with epidote. The augite is almost completely altered to viridite, although a few remnants are still recognizable. This rock also contains, as stated, coarser grained segregations in which black hornblendes are readily distinguished by the unaided eye. In thin sections these are of a deep brown color and strongly dichroic. Some of the individuals are so compact and well defined in crystalline outline as to indicate that they are original constituents of the rock; while in other cases the presence of a hornblende border of varying width about an augitic core indicates unmistakably a paramorphic origin. The hornblende has, in its turn, undergone in certain cases the viriditic alteration. This is the only one of the Nantasket rocks in which I have been able to find paramorphic hornblende so distinctly characterized as to leave no doubt of its origin, although this is suggested by sections from dike 29.

A few small, grayish, wedge-shaped crystals of sphene are present. Feldspars, in most part, are considerably altered; but in a few instances are still clear and show the twinning striæ very plainly. There is much viridite, which obscures everything.

Dike 34.—Differs in no essential particulars from 29 and 31, though the section does not show the hornblendic segregations.

Dikes 40 and 41.—These two dikes are without doubt identical with the preceding, though nothing in the present compo-

sition goes to show that they were not originally diorites rather than diabases. So far as examined, not a particle of fresh augite remains; but an occasional fragment of brownish hornblende still exists so far unchanged as to be recognizable. The light green viridite is everywhere present, interspersed with magnetite grains, particles of epidote and apatite needles. A few of the feldspars are still fresh, though here also the viriditic alteration has prevailed. My reasons for calling the rocks diabase is that the products of decomposition, their form and their arrangement, are identical with those of the augitic rocks throughout the entire area under examination.

Third Series.

Dike 62.—Very fine grained and compact; nearly black. Under the microscope this rock shows a marked deviation from the prevailing types of structure as already described. In the thin section it shows beautifully fresh and clear porphyritic plagioclases, in single lath-shaped forms and in cruciform aggregates; together with altered olivines and occasional clear but corroded augites, imbedded in a dense fine-grained ground-mass of small plagioclases, augites and iron oxide. The olivine, though changed completely to a chloritic product, is readily recognized by its form and irregular fracture-lines. The augites are confined almost wholly to the ground-mass; but the section shows a few corroded porphyritic forms, as above noted. All are fresh and free from enclosures. The iron oxide occurs abundantly in rod-like forms, crossing one another at nearly right angles, producing grate-like or barred structures. This diabase is the least altered of all that has been examined.

Dike 66.—Of medium coarseness, and to the naked eye apparently granular crystalline and fresh. This rock is quite different in general appearance from any yet described.

Macroscopically it is a well compacted, quite fresh-appearing rock, of a deep purplish black color, in which hornblende or au-

gite is apparently the chief constituent. Under the microscope, however, the section is found to present, aside from the apatite needles, not a single original mineral in a fresh and unaltered state; but the entire mass of the rock is filled with small amorphous grains and dust-like opaque particles of a black color, interspersed throughout a dirty grayish groundmass, with only here and there a small fragment of an augite crystal or colorless portion of feldspar, in which in a few instances twinning striæ were still apparent. Scattering grains of epidote and shreds of a brownish mineral, evidently hornblende, complete the list of determinable minerals. The black opacite and the gray amorphous material are evidently derived from the decomposed augite; it being not infrequent to find the border of a crystal irregularly outlined by the larger grains, while interiorly is the gray material and other black grains. The form and size of the black grains is such as to render their identification by the microscope alone impossible. The pulverized rock is, however, strongly magnetic; and after long digestion with hydrochloric acid the solution gives a faint reaction for titanium. The augitic alteration would in this case seem to be similar to that of the hornblende in certain New Hampshire diorites described by Hawes.[1] That the altered mineral in this case is augite and not hornblende is proved by a few unchanged particles still remaining and the form of the outlines still preserved. Viridite, so abundant in the other rocks described, is here entirely lacking.

DETAILED STRUCTURE OF NANTASKET.

The main purpose of this section is to set forth as fully as may seem desirable the facts upon which the generalizations of

[1]Geol. of New Hampshire, Vol. III., part IV., pages 43 and 66.

the preceding sections are based; not forgetting that the highest interest attaches to the relations and especially to the contact phenomena of the bedded rocks—conglomerates and lavas. For present convenience, as well as in the interest of future students of the Nantasket ledges, each principal mass or area will, as regards the sedimentary rocks and associated lavas, be described somewhat independently and in topographic order, reserving the general correlation, the complete elucidation of the stratigraphy, until the close of this systematic itinerary. The structural details of the dikes, or the intrusive igneous rocks, will then be presented, in both chronologic and topographic order.

The Atlantic Shore or Coastal Area.

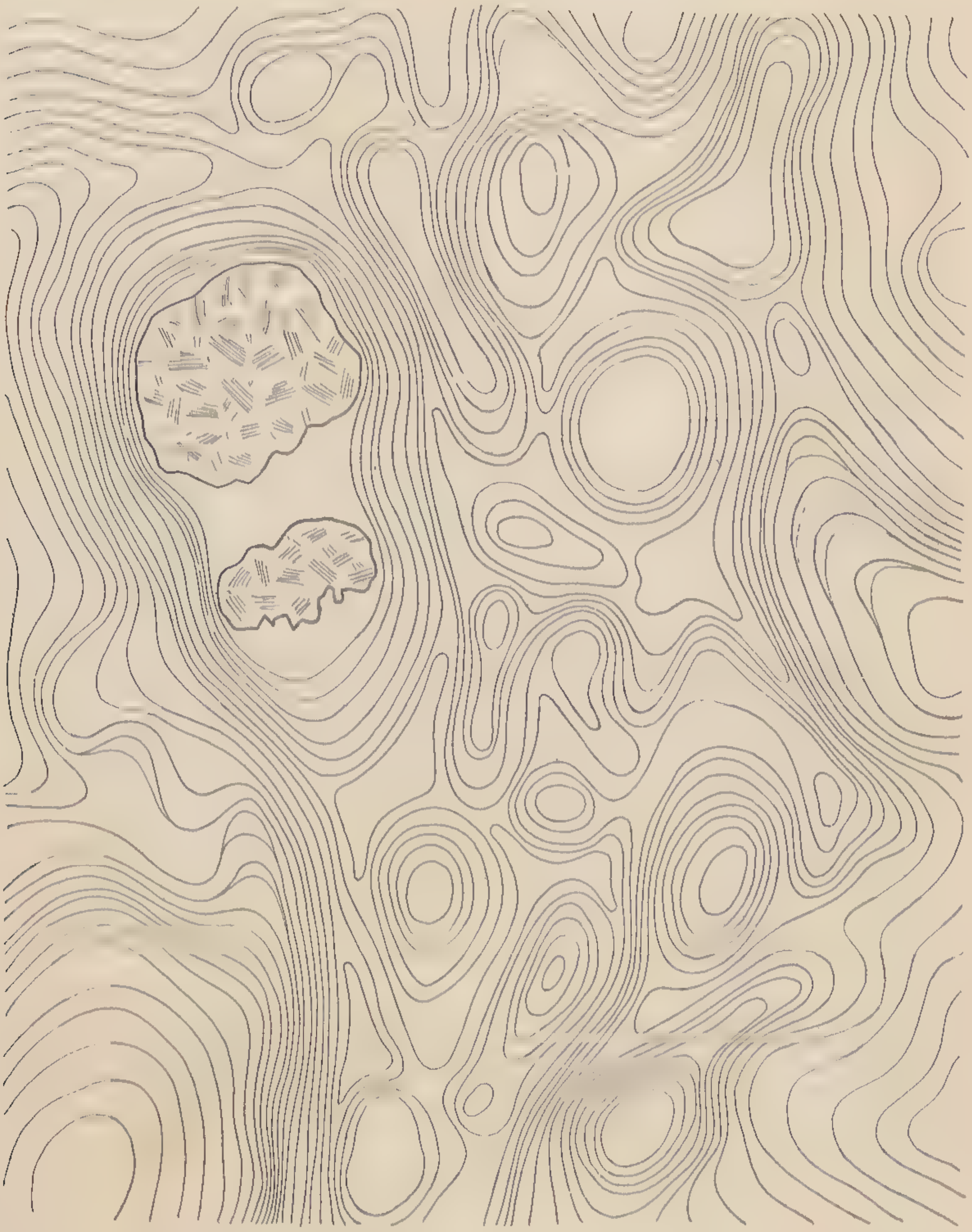
This area, extending from Nantasket Beach to Black Rock, includes the most accessible and the most frequently visited of the Nantasket ledges; and it is a fortunate circumstance that, although the melaphyr largely predominates here, some of the more characteristic features of Nantasket geology are well exhibited at this natural starting point. The granite, however, is wholly wanting; and its interesting relations to the conglomerate cannot be observed in this part of the field.

Long Beach Rock Conglomerate.—The most northerly part of Long Beach Rock is a somewhat isolated, half-tide ledge of conglomerate. It contains many pebbles, mostly small, of granite and felsite, and also many larger pebbles of different varieties of melaphyr. From the latter we may infer that this bed is underlain by melaphyr, and that it is probably not the lowest or basal conglomerate. Eight or ten feet below the top of the conglomerate is an intercalated layer of fine, hard, red sandstone, eighteen inches thick; and conformably overlying the conglomerate, are six to twelve inches of a beautifully banded, greenish slate of flinty hardness. The sandstone and slate show that the strike is N.65° E.[1], and the dip S.E. 15°-20.°

[1] All azimuth directions given in this paper are referred to the true meridian.

FIG. 1. SECTION ACROSS LONG BEACH ROCK. SCALE. 1 INCH = 40 FEET.
The horizontal dotted line marks the low-tide level.

Melaphyr and Tuff.—The Long Beach Rock sediments are overlain conformably by a compact green melaphyr. The contact of the melaphyr and slate is exposed for about one hundred feet along the strike; and at several points there are fine transverse sections of the contact, which is accessible only at low tide. Fig. 1 is a general section of both the conglomerate and melaphyr. The irregularities of the actual contact, and especially the bending of the subjacent laminæ of slate, as well as the intense induration of this rock, which has been baked to a good semi-porcelainite, indicate that it was but imperfectly consolidated, if not entirely plastic, when the melaphyr flowed over it. But, on the other hand, the exquisitely beautiful brecciation and miniature faulting exhibited on some of the wave-washed surfaces show that before the disturbance ceased the clay had become brittle enough to break. This fascinating exposure is the gem of Nantasket geology; and it is hoped that it may long remain unmutilated, to delight and instruct future students. That the eruption was submarine, or at least essentially contemporaneous with the deposition of the sediments, is beyond reasonable doubt; although it is probable that the thin layer of green slate on which the melaphyr immediately

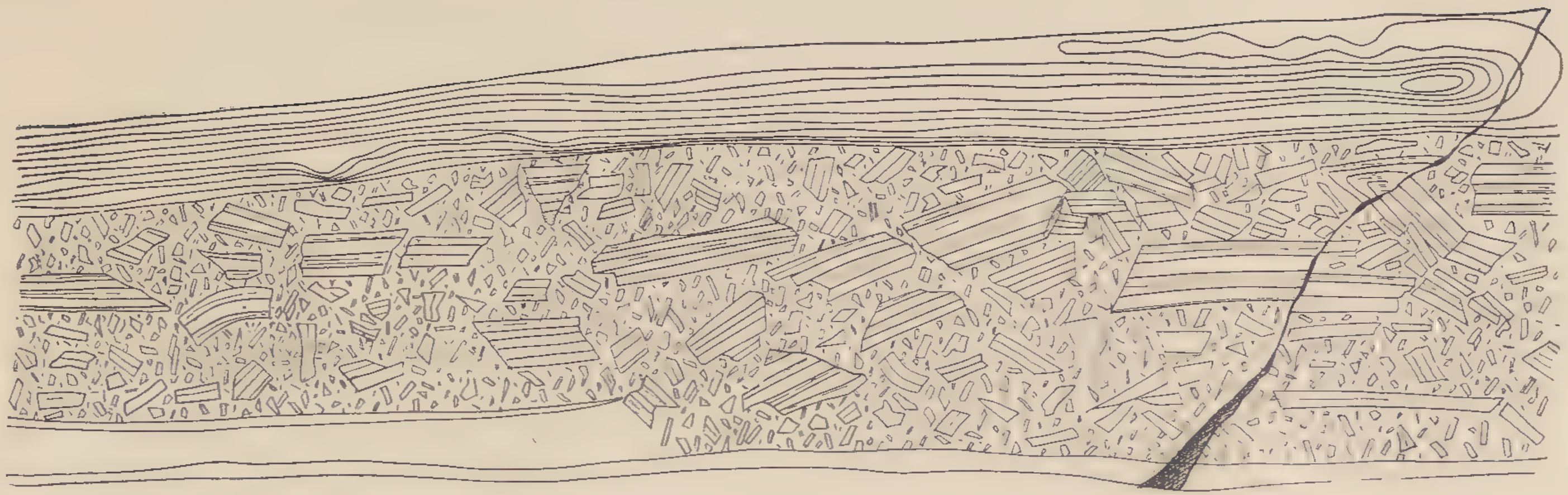


WAVE-WORN SURFACE OF THE INTENSELY HARD, GREENISH, BANDED SLATE OR TUFF SEPARATING THE CONGLOMERATE AND MELAPHYR ON LONG BEACH ROCK. LINEAR SCALE, ONE HALF NATURAL SIZE.

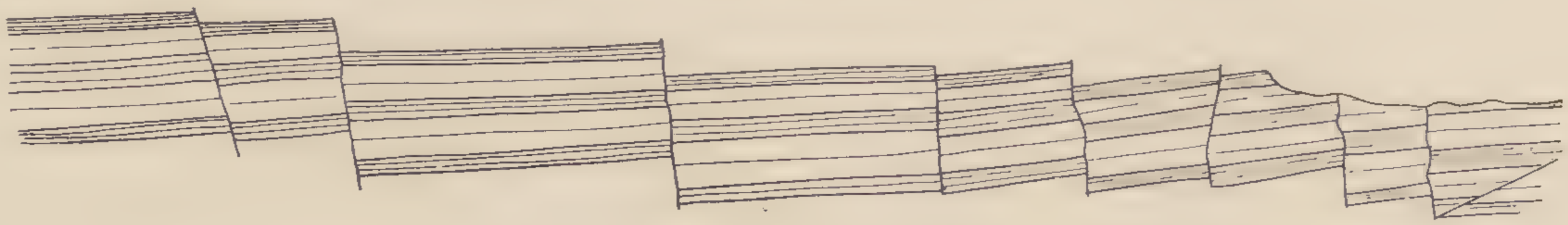
[Reduced by photography from a tracing made directly from the stone.]

This impalpably fine sediment was deposited quietly and uniformly over the uneven, pebbly surface of the conglomerate; and consequently where erosion has cut down nearly to the top of the conglomerate, each pebble determines the center of a series of concentric lines, the outcropping edges of the laminae of slate. In the portion of the eroded surface here represented, the banded slate has been worn away sufficiently to actually expose only two pebbles of the conglomerate.

In the upper part of this thin bed of tuff, where it experienced more distinctly the mechanical stresses of the overflowing lava, the layers are, to some extent, finely brecciated and faulted, as shown in the illustrations on the next plate.



A HIGHLY BRECCIATED PORTION OF THE THIN BED OF INDURATED TUFF ON LONG BEACH ROCK.
LINEAR SCALE, ONE THIRD NATURAL SIZE.



A SERIES OF MINUTE FAULTS IN THE SAME BED. LINEAR SCALE, ONE THIRD NATURAL SIZE.

[These two figures also are essentially *fac-similés*, having been produced in the same way as the preceding plate.]

rests should be regarded as an exceedingly fine volcanic tuff, the eruption of liquid lava having been preceded by an outburst of volcanic ashes. The influence of the lava flow has also penetrated the conglomerate, the layer of sandstone eight feet below being almost as thoroughly indurated as the slate.

The breadth of the melaphyr is fully two hundred feet and its actual thickness probably not far from sixty feet. It is, for the most part, rather compact and of a dark green color. But toward the top especially it is full of irregular segregations of quartz and shows, in a rather large way, a very distinct and somewhat wavy flow-structure, resembling bedding and parallel with the stratification of the underlying conglomerate. Irregular veins and masses of compact and impure epidote, occasionally of considerable size, also occur in the upper part of the melaphyr. It is very plain that the entire thickness of melaphyr is to be regarded as forming one simple and normal flow homogeneous and massive below, but superficially brecciated and scoriaceous.

This great lava-flow is undoubtedly continued eastward in the outermost part of the ledge exposed at low tide north of Centre Hill; and it appears probable that further east the line of strike changes so as to connect Little Black Rock with the same bed. This islet, which is about four hundred feet long and half as broad, is entirely composed of melaphyr very similar to that on Long Beach Rock, except that it is in part amygdaloidal.

The prominent ledge at the northwestern base of Atlantic Hill, and partially isolated by the sands of Nantasket Beach, is chiefly a distinctly and evenly bedded greenish gray sandstone, alternating, especially in the upper part, with layers of greenish and rather indistinct, small-pebbled conglomerate. This conglomerate is made up of much smaller pebbles, and is in every way very distinct from that on Long Beach Rock. The pebbles are mainly more or less angular fragments of melaphyr, are not well assorted, the coarsest and finest material being

mingled indiscriminately, and, with the exception of a rare pebble of felsite or granite, the entire ledge, sandstone as well as conglomerate, appears at first to have been derived from the Long Beach Rock flow of melaphyr. There is much, however, in both the composition and texture of this mass to suggest that it may be a true volcanic tuff, a record of explosive volcanic action either at the close of the eruption already described or at the inception of the similar littoral or submarine eruption by which this bed was covered. It will be observed that this interpretation is adopted on the map, the lava-flows being thus supposed to have followed each other so closely over this marine area as to preclude the deposition of any appreciable amount of the ordinary or normal sediments between them.

This bed of tuff strikes N. 65° E., and dips S.E. 15°. Its full breadth appears to be exposed, viz., 120 feet, equal to a thickness of about 30 feet. It can be traced for about 300 feet along the base of Atlantic Hill, rising at the highest point some 20 feet above the beach. The line of strike carries it directly across the shingle beach connecting Long Beach Rock and Atlantic Hill. I have been unable to positively identify it on the low-tide ledge north of Centre Hill; but it seems impossible to doubt that it crosses here, although probably with diminished thickness. It appears necessary, also, to suppose that the tuff overlies conformably the melaphyr of Long Beach Rock, although there is no exposure of the contact. If the tuff extends so far to the eastward, it must pass to the north of Gun Rock and between the two Black Rock islets.

This old ash-bed is overlain clearly and conformably by a second bed of melaphyr, the contact being well exposed at several points along the northern base of Atlantic Hill. The contact is similar to that between the green slate and overlying melaphyr on Long Beach Rock — conformable in the general view and yet with many minor irregularities. Fig. 2 shows the contact as it appears at the edge of the beach, below the bath house and near the foot of the Atlantic House steps. It is clearly such a contact as would naturally result from the

flowing of liquid lava over unconsolidated sediments. And the attention of those who may see in the minor unconformities of the contact evidence that the melaphyr is really intrusive is called to the fact that no detached fragments of the tuff or sediment are observed in the base of the melaphyr.

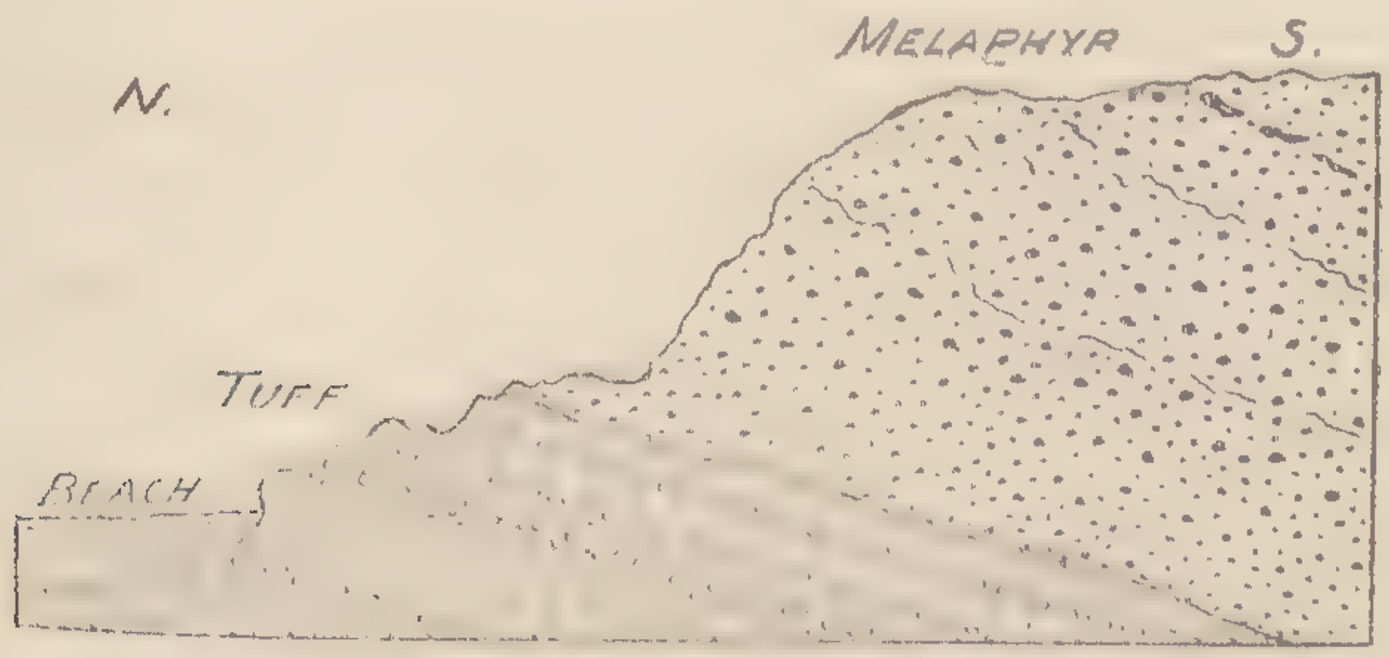


FIG. 2.—CONTACT OF TUFF AND MELAPHYR AT THE NORTHERN BASE OF ATLANTIC HILL.
SCALE, 1 INCH = 12 FEET.

The thickness of the melaphyr, near the bath house, is about twenty feet; and it appears to increase eastward. This is very clearly a second lava-flow, and not an intrusive bed; and in lithological character it is very similar to the first, being chiefly dark green and compact. It is sometimes, however, more brecciated; but exhibits the same ill-defined segregations and veins of quartz and epidote. This flow can be traced eastward along the base of Atlantic Hill to Valley Beach, between Atlantic and Centre Hills; and it undoubtedly forms the landward end of the low-tide ledge north of Centre Hill.

Valley Beach is bounded by two good transverse sections of the formations. Atlantic Hill ends here in a small cliff, which shows the following *thicknesses* from below upwards (Fig. 3): The second melaphyr, already described, about 30 feet; volcanic agglomerate and tuff, 7 feet; melaphyr, 9 feet; agglomerate and tuff, 25 feet; and then melaphyr extending southward indefinitely, or beyond the end of the section.

The first fragmental bed or tuff in this section measures 7

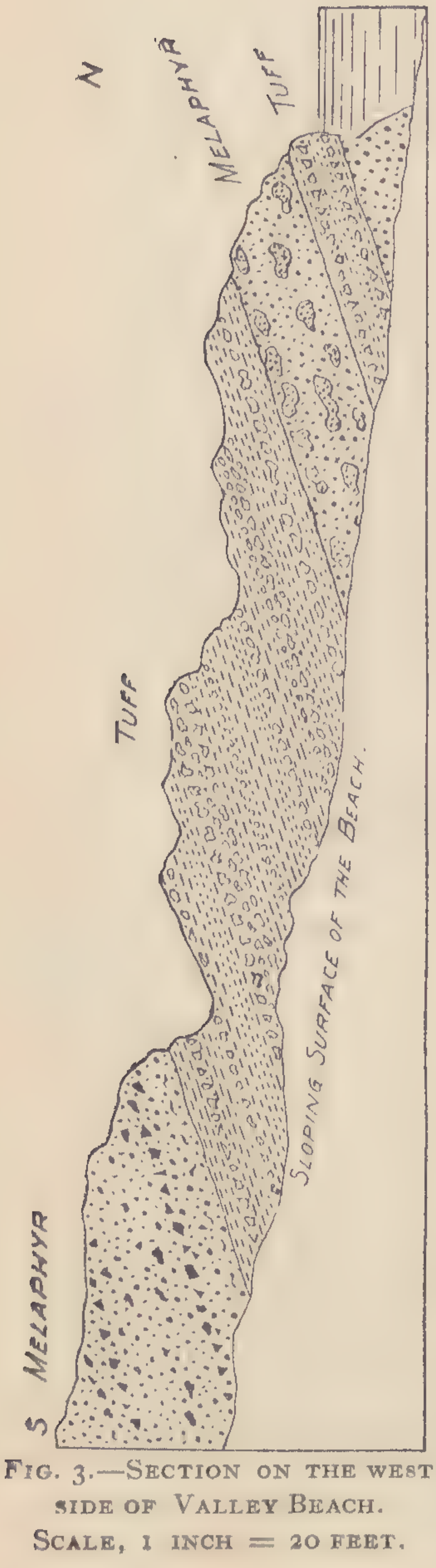


FIG. 3.—SECTION ON THE WEST SIDE OF VALLEY BEACH.
SCALE, 1 INCH = 20 FEET.

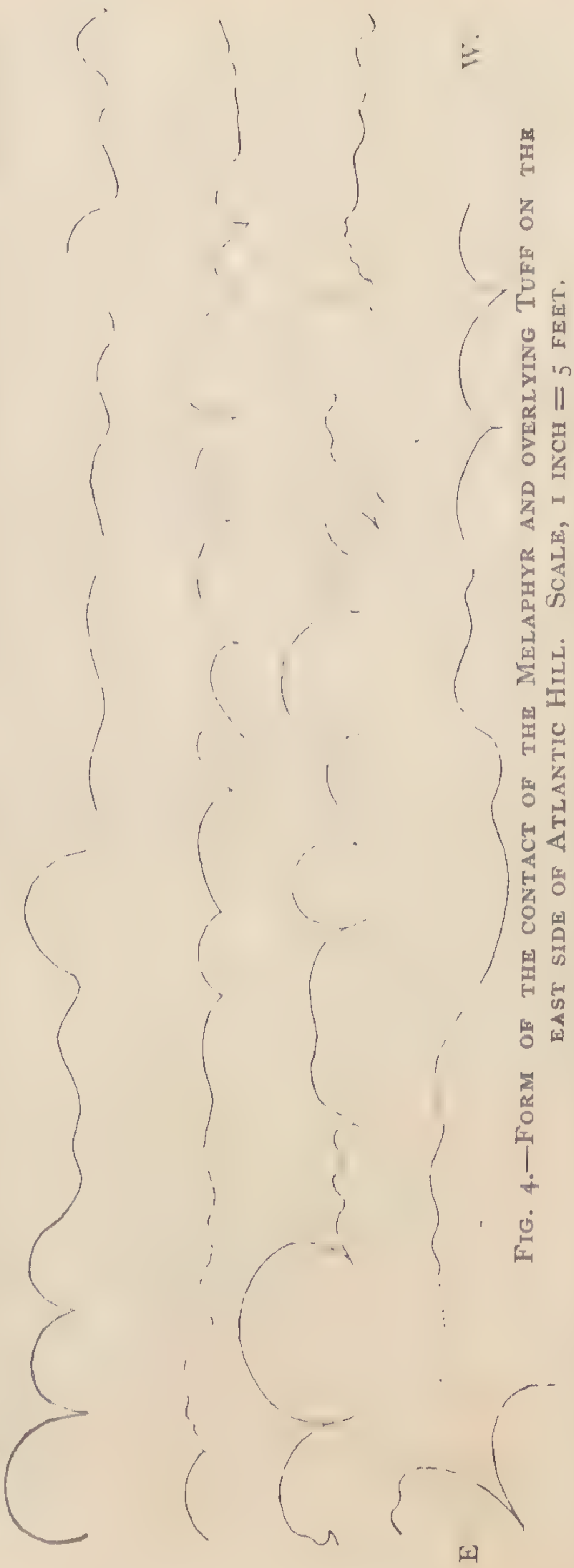


FIG. 4.—FORM OF THE CONTACT OF THE MELAPHYR AND OVERLYING TUFF ON THE EAST SIDE OF ATLANTIC HILL. SCALE, 1 INCH = 5 FEET.
Each line is the right-hand continuation of the one next above it.

feet on the cliff, but grows narrower westward and appears to die out entirely between 200 and 250 feet from the cliff. It is probable, however, that the tuff really persists until it passes the edge of the overlying melaphyr, and is merged with the next bed of tuff, as shown on the map.

The boundaries of this tapering edge of the fragmental bed are quite irregular. This is especially true of its lower surface, where it rests upon the second melaphyr. The form of this contact for 130 feet west from Valley Beach, or as far as it is clearly exposed, is shown in Fig. 4; for the sake of convenience, however, the curves are represented as following each other more nearly in the same direct line than is actually the case. The upper surface of the melaphyr presents smoothly rounded hemispherical protuberances or swellings one to three or four feet in diameter. The actual boundaries of adjacent protuberances may usually be traced below the surface of the melaphyr; and some of these remarkably regular and graceful curves thus describe two-thirds or three-fourths of a complete circle. Probably the majority of the curves are really sections of rounded ridges or rolls,—the surface flow-structure of the lava. But it is very noticeable that these prominences exhibit semicircular profiles to some extent on both the transverse and longitudinal sections of the bed, suggesting hemispherical tumefactions or superficial bubbles formed on the liquid lava.

It seems impossible to regard these features as the product of erosion; they must be entirely original; the actual surface of the fresh submarine lava-flow, which was covered almost intact either by the ashes accompanying a second flow or by the débris worn from adjacent masses. The fragments are mainly angular, ranging in size from dust to three inches in diameter; and this is clearly a thin, local deposit on the surface of the sheet of lava.

The well-marked north-south depression separating Atlantic and Centre Hills, and terminating at the lower end in Valley Beach, does not seem to be occupied by a dike, for the melaphyr shows half way across the bottom of it, and there is not a ves-

tige of dike rock to be seen *in situ*; nor does it appear to be chiefly due to faulting, but rather to rapid erosion along a series of close parallel joints. There has been a little slipping, however; for on tracing the thin bed of tuff across the one-hundred feet of beach, we find its outcrop shifted about twenty feet to the south, indicating an upthrow on the east of perhaps five feet. The melaphyr between the two walls, may, of course, have dropped down almost any amount, producing two converging and compensating faults. East of the beach the bed of tuff already described crosses the ledges diagonally to the shore in about one-hundred feet, passing out of sight under the water without any sensible change of dip or thickness.

Returning to the west side of Valley Beach, the melaphyr, nine feet in thickness, overlying this tuff is found to be quite conformable, the contact showing only the minor irregularities that would naturally be developed where a stream of lava flows over unconsolidated sand and gravel. The contact is not always a sharply defined line, but the lava is enough mixed with the sand so that the two rocks are blended through a thickness of several inches. The swelling curves characterizing the lower surface of the tuff are not observed above it.

The structure of this melaphyr, which is really the third flow, reckoning from the conglomerate on Long Beach Rock, is quite peculiar. A compact, greenish matrix encloses irregularly rounded amygdaloidal masses from two inches to two feet in their longest dimensions. The amygdules are usually arranged in concentric lines or zones parallel with the exterior; and the coarsest amygdules are sometimes towards the periphery and sometimes in the centre. These masses are quite clearly distributed in irregular lines parallel with the bed; and this fact, as well as the great number of the masses, is decidedly unfavorable to the view that they are true volcanic bombs. But the best explanation which has occurred to my mind is, perhaps, not wholly satisfactory, viz., that, during the flowing of the lava, vesicular layers and crusts were, by the unequal flowing and revolving motions, broken up and the fragments rounded

into the forms we now see. East of Valley Beach, along the north front of Centre Hill, this melaphyr expands rather rapidly; and it is very obvious that while the rounded amygdaloidal masses or pseudo-bombs are thickly and pretty uniformly scattered through the middle and upper parts of the flow, they are almost entirely wanting in the lower part. They continue to form a prominent feature of the upper part of the melaphyr about half way across Centre Hill, and then die out rather gradually. Beyond this point the identity of the melaphyr as a separate flow is lost, since it is indistinguishable from the overlying melaphyr, with which it is here in direct contact. That the third melaphyr actually extends quite across Centre Hill, if not across Gun Rock, there can be no reasonable doubt. This flow is of exceptional interest, not alone on account of the pseudo-bombs, but also because it affords, perhaps, the only instance in the Nantasket area where the tapering edge of a bed of lava can be clearly traced. It certainly thins out rapidly toward the west, and, as stated, can not be followed much more than two hundred feet west of Valley Beach, the underlying and overlying tuffs appearing to come together at this point. It will not escape attention that the amygdaloidal masses are thus found where we should most naturally look for them — in the marginal and superficial portions of the flow.

The second bed of tuff in the Valley Beach section, or that overlying the amygdaloidal melaphyr, is lithologically similar to that below the melaphyr; but it is three times as thick, and can be traced westward the entire length of Atlantic Hill, with no sensible change of dip or thickness, passing under the beach on the west where the County or Beach road first reaches the base of the hill. It is well exposed near the Atlantic House steps, just above the bath house; from here it continues around the hill a little above the middle of its height; and then gradually descends to the level of the beach on the east. The continuity of the bed is clear; but its strike must change from N. 65° E. on the west to at least N. 75° or 80° E. on the east side of the hill. Its upper and lower contacts are

clearly exposed at several points, and are favorable to the view that the melaphyrs are contemporaneous. It consists, like the other beds of tuff, almost wholly of more or less angular and imperfectly assorted fragments of melaphyr imbedded in a distinctly stratified cement of the same character. On the west side of the hill it rests directly upon the second melaphyr; while in the vicinity of Valley Beach the second tuff and the third or amygdaloidal melaphyr are interposed, as already explained. East of Valley Beach it is scantily exposed, and can not be traced much beyond the Waverly House. But it is here, seemingly, somewhat interstratified or mingled with the underlying amygdaloidal melaphyr.

Above the last described or third tuff comes the great body of melaphyr forming all the remaining portions of Atlantic and Centre Hills and extending south to Conglomerate Plateau, as shown on the map. The outcrops are so numerous over this area that there is absolutely no room to doubt the essential continuity of the melaphyr. Its breadth, measured from the third tuff, along Valley Beach Avenue, is nearly 1400 feet, corresponding to a probable thickness of more than 300 feet. Or, classing the three beds of tuff as fragmental lavas, as the facts appear to warrant, and thus regarding the volcanic series as essentially continuous back to the conglomerate on Long Beach Rock, the breadth of the entire series of three tuffs and four melaphyrs is, in round numbers, at least 1800 feet, and thickness 450 feet.

The great mass of melaphyr above the third tuff is fairly uniform lithologically. It is usually more or less brecciated, with numerous highly irregular and limited segregations of vitreous quartz and chalcedony, as well as epidote. But sometimes it is much more distinctly brecciated, especially immediately above the third tuff. On Atlantic and Centre Hills it is rarely amygdaloidal or quite compact in texture. Near the southern border of the melaphyr area, on the north side of Willow Ledge Hill, it encloses about twenty feet in thickness of greenish tuff and agglomerate. The green arenaceous tuff is

interstratified, especially in the lower part of the section, with a bright red, slaty rock, which is somewhat contorted; and in the upper part of the section with the agglomerate, which is chiefly composed of quite small, but mostly angular fragments of melaphyr. These beds, which are very distinctly stratified throughout, strike about N. 80° E., dip S. 15°, and are overlain conformably by the melaphyr; but the lower contact is not exposed. On the west they are quite certainly cut off by a fault, and this, as shown on the map, is probably also their fate on the east. At any rate, the melaphyr clearly crosses their strike in this direction, and it is impossible to trace them for more than three hundred feet. A red slate or tuff similar to that found here, crops out just west of the Rockland House, accompanied, apparently, by agglomerate, although this may be only the ordinary conglomerate or puddingstone. The correlation of these red outcrops would require us to postulate dislocations which are not indicated on the map and for which there is no independent evidence. It appears wiser, therefore, to regard them as local and non-synchronous accumulations of volcanic dust and lapilli.

The melaphyr immediately northeast of the Rockland House is similar to that on Atlantic Hill, and is undoubtedly a continuation of it; and the same is true of the melaphyr forming Gun Rock and its neighboring ledges. The beds of tuff on the north side of Atlantic Hill cannot be traced west of the abrupt western slope of the hill, perhaps for want of outcrops; nor can they be followed eastward more than half way across Centre Hill. But in this direction the various flows of melaphyr are, apparently, united; and in the Gun Rock district there is not a trace of any sedimentary rock, but the true conglomerate and the fragmental lava or tuff are alike wanting. It would be easy, of course, to explain the absence of the tuffs by faulting, but it is, perhaps, more probable that these fragmental lavas were never spread over this area. The submerged or half-tide ledge east of Gun Rock (see map) is about three hundred feet long at low tide, and consists wholly of melaphyr similar to that of Gun Rock.

There is, apparently, no reason to doubt that all the mela-

phyr described up to this point, with the included tuffs, on Rockland, Atlantic, and Centre Hills, Gun Rock, the submerged ledges and Little Black Rock, belongs to one great bed or sheet having an approximately east-west trend and southerly dip and overlying the conglomerate forming the north end of Long Beach Rock. Throughout this great mass, however, there are many indications that it is really composite, consisting of a succession of flows; which either were not submarine, or followed each other so rapidly as to preclude the formation of any sensible thickness of intervening sediments. The included beds of tuff show this very clearly. The zones of brecciated melaphyr, the fractures being marked by segrations of silica and impure epidote, seem to show it. And there are often curving lines, such as have been described at the base of the second tuff (Fig. 4), which appear to mark the contact of two successive flows.

On the north side of Centre Hill, near the end of Centre Hill Avenue, is another proof, in the form of a dike of melaphyr (No. 1, on the map), that this great bed is not throughout of the same age. Its compactness and general resemblance to the enclosing melaphyr, as well as the irregular contacts, mark this dike as probably contemporaneous with some later flow of this immediate series, although, of course, of later date than the flow which it is seen to intersect.

The general absence of the amygdaloidal texture in this melaphyr, except in the flow separating the second and third tuffs, is very noticeable; and this negative character, as well as the prevalent brecciation, contrasts it strongly with the most of the other masses of melaphyr or basic lava in the Nantasket area. In fact, as Mr. Merrill's descriptions show, both the structure and composition of this rock assign it a position between the ultra basic lava or typical melaphyr, and the more acid lava or porphyrite of this region.

Porphyrite.—The remaining rocks and islets, east of Gun Rock, constitute a very typical area of porphyrite, bounded on

the north, apparently, by the eastward extension of the great belt of melaphyr indicated by Little Black Rock, and on the south by the conglomerate of Green Hill. Although, as Mr. Merrill states, this rock resembles the melaphyrs more in its general aspect than does the porphyrite of the western part of the Nantasket area; chemical analysis shows that it is as acid as any porphyrite in this district. It is somewhat variable in its microscopic features, but usually presents a compact, or apparently felsitic, dark gray or purplish to nearly black, base, enclosing numerous porphyritically developed feldspars or minute aggregates of epidote. It is never amygdaloidal, and rarely distinctly brecciated; but exhibits at several points a well-developed striping or flow-structure.

Black Rock, which is about seven hundred feet east and west, and half as broad, is a continuous and almost perfectly bare mass of porphyrite. Fluidal lines are very plainly marked in a portion of the porphyrite, with usually an approximately east-west trend and a gentle southerly dip, thus proving that the normal attitude of the rocks, so clearly exhibited about Atlantic Hill, is preserved to the very eastern limit of the Nantasket area. Near the middle of the west half of the island, a considerable mass of porphyrite is split up by close, parallel east-west and nearly vertical joints so as to present a very shaly appearance. The character and especially the attitude, or dip and strike, of this structure indicates that it is possibly true cleavage rather than jointing, and analogous to the foliation of the diabase on Calf Island.[1] The small island north of Green Hill (Green Hill Rock) is another mass of gray and purplish porphyrite, with fluidal lines; and the half-tide ledge between this and Black Rock exhibits a similar constitution. Since the porphyrite of this area is exposed only in these three insular masses, it is manifestly impossible to determine with certainty either its boundaries, its thickness or its relations to the bordering melaphyr and conglomerate. If, however, we may follow the lithologic indications and correlate it with the porphyrite of the western area, it must, as will appear later, be referred to a horizon below this

[1] Proc. B. S. N. H. xxiii., 455.

melaphyr and conglomerate and thus owe its exposure to extensive faulting. The map, it will be observed, has been constructed in accordance with this view ; and reference to the table of Nantasket strata on page 24 will afford some idea of the magnitude of the displacements which it involves,—at least 50 feet on the side toward the conglomerate and 400 feet on the side toward the melaphyr.

Indications are not wanting that Black Rock is near the point or centre of emission of the Nantasket porphyrites. One evidence of this is the seemingly great thickness of the porphyrite in the Black Rock area, and its more crystalline character as compared with the porphyrite in the western part of Nantasket. The most important fact pointing to this conclusion, however, is the series of porphyrite dikes on the Cohasset Shore east of Green Hill. The most casual observation shows that the approximately north-south dikes on the Cohasset Shore can not all be referred to the third system of diabase dikes ; but besides the three well-defined systems of dark-colored, finely crystalline diabase dikes, there is evidently a fourth system having a general north-south trend, consisting of a distinctly greenish rock, which varies in texture from apparently felsitic and porphyritic to visibly holocrystalline or nearly so. The dikes of this kind are not only lithologically but chronologically distinct, for they are repeatedly cut by both the east-west and north-south diabase dikes ; and hence, although agreeing approximately in trend with the newest series of dikes, they must be regarded as the oldest system exposed on this shore.

My interest in this oldest system of dikes was not aroused so much by the clear proof of their age as by the marked lithological resemblance which they bear to the more acid lavas or porphyrites of Nantasket, and especially to the porphyrite of the Black Rock area. Except that the porphyrite flows, although often visibly epidotic, are rather rarely distinctly greenish in color, while the dikes of this system are always so ; and that the dikes are more crystalline than the effusive rocks, as we should naturally expect ; while the latter exhibit commonly

a striping or flow-structure which is wanting in the dikes; the superficial resemblance is certainly very obvious, suggesting at once that the dikes may be the channels or vents through which the effusive porphyrite reached the surface, or at least referred to the same eruptions — the same period of volcanic activity.

Mr. Merrill has found (page 38) that, although somewhat more crystalline, these dikes are essentially similar in microscopic characters to the Black Rock poryhyrite; and in order to further test the validity of this hypothesis a typical example from one of these dikes was submitted, through the kindness of Dr. T. M. Drown and Mr. G. F. Eldridge of the Massachusetts Institute of Technology, to partial chemical analysis, with the following result, the mean of four accordant determinations: silica, 60.84 per cent.; alumina and ferric oxide, 20.12 per cent.; with which may be compared the percentage of silica —58.25 per cent.—afforded by the Black Rock porphyrite. As in the case of the melaphyr (page 38), we find that the dike is slightly more acid than the effusive portion of the eruption; its more crystalline character causing it, apparently, to yield less completely to the deep-seated alteration, thus reversing the normal relative proportions of silica observed in recent eruptive rocks.

That the classification of these dikes by the superficial characters is unsafe is shown by a second analysis, by Mr. Eldridge, from another dike of the series. This afforded, as the mean of four accordant determinations, silica, 48.47 per cent.; alumina and ferric oxide 31.53 per cent.; and if not a true diabase, it should, apparently, be associated with the more basic melaphyrs of Nantasket. Obviously, then, a systematic microscopic and chemical examination of these dikes will be required for their accurate classification; and we can now only assume that, as appearances indicate, they are chiefly porphyrite.

A more detailed description of these dikes will be presented later, in the systematic account of the dikes of this region; and all that I desire now is simply to call attention to the following points: — (1) That they are probably of the same age as the

surface sheet of porphyrite and connected with the vents through which it was extruded. (2) That no dikes of this character have been discovered west of Green Hill or more than one mile east of it. (3) That they all have, without exception, a northerly trend, *i. e.*, they either run toward the Black Rock porphyrite or so as to intersect the eastward extension of its line of strike. And yet (4) none of them have been found breaking through the porphyrite itself, these dikes being thus comparable with the great melaphyr dike (No. 2), since in both cases the complete erosion of a portion of the effusive accumulations was essential to expose the intrusive masses — the roots of the eruptions — in the underlying granite.

Green Hill Conglomerate.—The prominent ledge of conglomerate which has been laid bare by the wearing away of the northern slope of Green Hill, is probably, as the fault-lines of the map indicate, a part of the great bed forming Folsom's Island and Conglomerate Plateau; but it appears more convenient to describe it in its geographic than in its geologic sequence. The ledge is about four hundred feet long from northwest to southeast, and shows throughout a southeasterly dip of 20° to 30°, giving an apparent thickness of perhaps 175 feet. Beginning on the southeast, there are 10 or 12 feet of medium conglomerate with distinct layers of reddish sandstone, showing the bedding well. This is underlain by about 60 feet in thickness of very coarse conglomerate, many pebbles, especially of granite, ranging from six to eighteen inches in diameter. The remainder of the section is conglomerate of a more normal character, varying from medium to rather coarse in texture. The conglomerate is composed throughout of well rounded masses of granite (coarse and pinkish), felsite of different varieties, and porphyrite; but, apparently, little true melaphyr. The porphyrite is mainly of compact, dark gray and brown varieties.

The Central Area.

This area embraces all that part of Nantasket east of the railroad and south of Atlantic and Centre Hills. The geological relations of the central area to the preceding or coastal area can be most easily traced in Willow Ledge Hill, which belongs in part to each. The summit and main mass of this elevation is a nearly square block of melaphyr and tuff. These rocks have been described in the preceding section, and the limits of this block are sharply defined on the map by the bounding fault-lines. The similar block of conglomerate on the west lies at a lower level, and its outcrops are separated from the volcanic block by a small artificial pond.

Both of these blocks are separated from the narrow ridge of conglomerate between them and Hull Street by the well-marked east-west depression occupied by Spring Valley Road. This depression is an evident fault-line, for the beds of conglomerate are so nearly horizontal that they must abut directly against the melaphyr; and the contact is undoubtedly oblique to the strike of the conglomerate. As indicated on the map, this is one of the great faults of the Nantasket region, traversing the entire area, from Strait's Pond to Weir River Bay. Few of the dislocations of this district are more obvious, and none are of greater structural importance. East of Valley Beach Avenue it is marked by the well-defined escarpment terminating the melaphyr of Centre Hill on the south, the conglomerate lying at a lower level here, under a meadow; while to the westward it coincides with the similar escarpment along the north side of Melaphyr Plateau, and, crossing the bay, defines approximately the abrupt northern shore of the western area. This line of fracture is thus clearly the natural boundary line between the coastal and central areas. But when we pass to the consideration of the direction and amount of the displacement along this line, and the stratigraphic relations of the two areas, a much more difficult problem confronts us. The escarpments, which

face now to the south and then to the north, evidently signify nothing but unequal erosion, appearing always on the side of the harder and more resistant rock, which is usually melaphyr. Facts will, however, be accumulated in the following pages pointing to the correlation of the conglomerate of Conglomerate Plateau with a horizon below that of the conglomerate on the extremity of Long Beach Rock; and hence to the conclusion that the downthrow is not only on the north, but that it must exceed the entire thickness of the melaphyr series of Atlantic and Centre Hills,— four hundred if not five hundred feet.

Although melaphyr occurs abundantly in the central as well as the coastal area, it is of a different and distinctly more basic type. It is very generally and often profusely amygdaloidal, rarely distinctly brecciated and never, so far as observed, accompanied by beds of tuff. The abundance of conglomerate south of the great fault, as well as the numerous faults, still further contrasts the two areas. It is, of course, quite possible, if not probable, that some of the faults of the coastal area have escaped discovery on account of the uniform character of the melaphyr in Atlantic and Centre Hills; and the great apparent thickness of this melaphyr ought, perhaps, to be regarded as largely due to repetition by faulting.

The alternations of the conglomerate and melaphyr in the central area are so frequent that it will be more convenient to describe these rocks together, following the order of the ledges or topographic features.

East shore of Nantasket Bay, Crescent Hill and Marsh Island.—These localities, forming a narrow belt across the western end of the central area, between the railroad and Melaphyr Plateau, may be conveniently described together, since, as the map shows, they present, as the result of parallel faulting, simply repetitions of certain beds of conglomerate and melaphyr. This tract is bordered by two well-marked north-south faults, and this primary fault-block is divided by no fewer than twelve transverse fractures, with the slips alternating in direction, and indicating the unequal rising and sinking of V-shaped blocks

(Fig. 8). Commencing at the north end, the first ledges of conglomerate and melaphyr rise somewhat abruptly from the marsh and the bay immediately south of the great east-west fault, and about five hundred feet, following the railroad, southwest of the broad, low outcrop of red and green slate or slaty tuff already described; and, as the map shows, the section is almost uninterrupted along the east side of the railroad from this point to the south side of Marsh Island.

FIG. 5.—SECTION SHOWING THE FAULT-DIKE (25) AND THE CONTACT BETWEEN THE THIRD CONGLOMERATE AND SECOND MELAPHYR, SOUTH OF THE FAULT. SCALE, 1 INCH = 30 FT.

It begins with the typical melaphyr of the central area, a dark green, evidently basic and highly amygdaloidal variety. The amygdules are not uniformly distributed; but they are especially abundant in a superficial layer of the rock from two to three feet thick. They are usually somewhat elongated and have a distinctly linear arrangement parallel with the layer; so that the flow-structure of the melaphyr as a whole is very marked. This mass of melaphyr has an exposed breadth of about forty feet north and south and is divided midway by dike 26; while it is abruptly terminated on the south by dike 25. This dike undoubtedly marks an east-west fault; for it is bordered by conglomerate on the south (Fig. 5). The fault probably hades with the dike to the north, and the melaphyr is clearly on the downthrow side. Not more than eight feet in thickness of the conglomerate are exposed before it is overlain by melaphyr.

The contact is very sharply defined, and most admirably exposed; and it is conformable to the flow-structure in the melaphyr, dipping south-southeast 5°-10°. This melaphyr appears to be identical with that north of the fault, the amygdules and flow-structure being even more pronounced; and they may be fairly regarded as parts of the same flow. The displacement here has been sufficient to conceal the conglomerate and to prevent its reappearance at the northern edge of the melaphyr, perhaps fifteen feet as a minimum. It should be stated, however, that the melaphyr on the north or downthrow side appears to be about horizontal or to have a slight northerly dip. Above the conglomerate, on the south side of the fault, the melaphyr has a breadth across the strike before we come to the overlying conglomerate of nearly one hundred feet and an apparent thickness of less than twenty feet. The true thickness, however, is probably not less than twenty-five or thirty feet, the apparent diminution being due to faults with the downthrow to the south accompanying dikes 29 and 31. Southwesterly or parallel with the railroad the sloping edge of the melaphyr flow is exposed broadly and almost continuously as far as dike 35. Near the railroad this dike marks the contact of the melaphyr and overlying conglomerate. The exposure is not very satisfactory; but there seems no reason to doubt that the melaphyr passes under the conglomerate conformably and without appreciable faulting. Following the contact to the northeast, it sweeps around in a curve concave toward the melaphyr. The two rocks are seen near together, but not in actual contact, until we come to the large inclined dike (31). Here a slight fault with the upthrow to the north brings the melaphyr into sight directly under the conglomerate (Fig. 6).

This conglomerate overlying the melaphyr is similar to that underlying it. It is, however, coarser and more irregular in composition, containing many rounded pebbles of granite and felsite 6 to 12 inches in diameter; and it is especially distinguished by holding many large pebbles of melaphyr, some of which are coarsely amygdaloidal and apparently identical with

that on which the conglomerate rests. The conglomerate outcrops broadly south of dike 35, forming a low hill; and a few streaks of sandstone show that the bed dips southeast about 10°, so that the thickness can scarcely exceed 25 feet. It is distinctly overlain on the southeast corner of the outcrop by a second flow of amygdaloidal melaphyr. The surface of the ledge slopes with the dip, and thus a thin layer of melaphyr covers quite a breadth of the conglomerate. A small triangular patch of the overlying melaphyr is also seen resting on the conglomerate immediately north of dike 35, indicating, apparently, a slight fault with the downthrow to the north on the line either of this dike or of the small dike (36) which is, probably, a branch of the main dike.

FIG. 6.—SECTION SHOWING THE FAULT-DIKE (31) AND THE CONTACT BETWEEN THE SECOND MELAPHYR AND THE FOURTH CONGLOMERATE, NORTH OF THE FAULT. SCALE, 1 INCH = 30 FEET.

Between dikes 29 and 31 the conglomerate crosses the north-south fault bounding Melaphyr Plateau and extends eastward into the melaphyr about 100 feet with a breadth of 75 feet. This extension, being on the upthrow side of the fault, is elevated above the rest of the bed some 20 feet. At its south-east corner the extension is overlain by amygdaloidal melaphyr of the same character, in precisely the same manner and with the same southeasterly dip (10°–15°) as at the southeast corner of the lower area. The extension is undoubtedly cut off by a fault on the south, with the downthrow in that direction, so that the contact of the conglomerate and overlying melaphyr in the

extension can not be traced far in the direction of the same contact in the main area. The conglomerate extension is bounded on the north by dike 29, which clearly marks a fault with the downthrow also, probably, to the south. Hence the melaphyr north of the conglomerate extension appears to be that normally underlying the conglomerate, and therefore distinct from, and separated by a fault from, that overlying the conglomerate.

The small meadow or marsh separating the conglomerate south of dike 35 from Crescent Hill must cover a fault with the downthrow to the north, as indicated on the map; for the bed of conglomerate first described and the underlying and overlying melaphyrs are repeated, with a stronger topographic relief and fewer dikes, in the hill. The conglomerate forms the summit of the northwestern part of the hill and extends entirely around the northern and western slopes, its outcrop thus having the form of a crescent. It is the irregular or mixed coarse and fine conglomerate, containing pebbles of amygdaloidal melaphyr as well as of granite and felsite. The contact with the overlying melaphyr is very plainly exposed on the summit. It is a true effusive contact and has a southeasterly dip of 10°—20°, being conformable with the bedding-planes of the conglomerate. This overlying melaphyr shows several distinct zones of amygdules, as well as other indications of flow-structure, and altogether exposes a thickness of 25 to 35 feet. The contact is also clearly exposed for fifteen feet at the base of the hill on the east side. The thickness of the conglomerate can scarcely exceed 30 or 35 feet. The underlying melaphyr exposes a thickness of about fifteen feet at the northwest corner of the hill, the contact descending both east and south. Near the middle of the west side of the hill the underlying melaphyr appears again, being elevated some ten feet above the railroad by an east-west fault with the upthrow to the north (Fig. 7). This fault gives the conglomerate and underlying melaphyr a distinctly synclinal structure in the

north-south line, the axis of the syncline dipping east 10° or more; which prevents the melaphyr from reappearing on the east side of the hill.

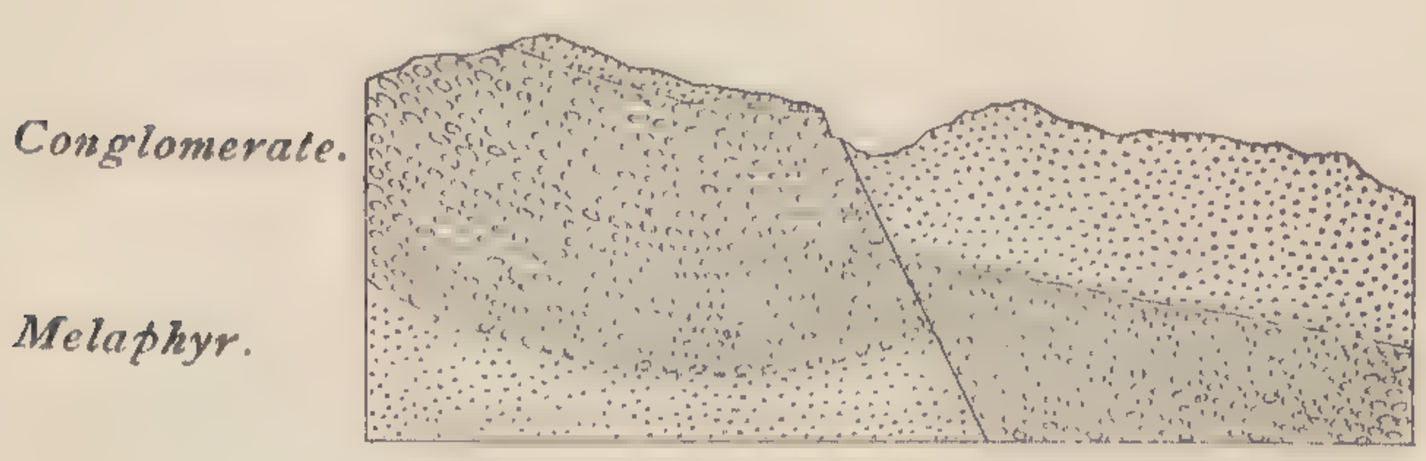


FIG. 7.—SECTION ACROSS THE FAULT ON THE WEST SIDE OF CRESCENT HILL. SCALE, 1 INCH = 50 FEET.

Crescent Hill is, in fact, divided by a series of east-west faults. Commencing on the north, the first fault is 65 feet from the northwest corner of Crescent Hill and exactly opposite the northern end of Great Hill. It downthrows to the north about eight feet, jogging the contact of the conglomerate and lower melaphyr; and, since it does not now cut the upper melaphyr, the effect is to increase the apparent thickness of the conglomerate. The second fault is thirty feet farther south. It hades S. 25° and downthrows in the same direction about eight feet, being compensating with reference to the first fault. Twenty-five feet farther south is a small dike (43) and the only one observed on the hill. Accompanying the dike, but not coinciding in plane with it, is the third fault, which hades and downthrows to the south, the throw being about eight feet, and the beds sloping steeply from the fault on the north. The next or fourth fault, seventy feet farther south, is that already referred to, on the west side of the hill. This is one of the plainest and most instructive faults in the Nantasket district. Figure 7 represents a general view of the fault as seen from the railroad, taking in the whole height of the hill. The fracture is still a well-marked and somewhat open fissure; and the jogging of the contact of the conglomerate and upper melaphyr shows that the downthrow is to the south and about

eighteen feet. The lower melaphyr very clearly rises to the south or toward the fault, and again to the north, giving the syncline already described. The fault trends N. 75° E., being in line with dike 37 in Great Hill; and it can be readily traced directly across the entire breadth of the hill, following approximately the boundary line between the conglomerate and upper melaphyr, and breaking this contact almost as distinctly on the eastern as on the western face of the hill. About midway between this fault and the southern end of the conglomerate is a fifth fault, which is the counterpart of the last, the downthrow being to the north and about 15 feet. It plainly jogs the contact between the conglomerate and upper melaphyr; and trends N. 75° W., being in line with dike 44 on Great Hill. Finally, at the extreme southern end of the conglomerate there appears to be a sixth fault, probably parallel with the last, but with the downthrow to the south. The amount of the throw, if to the south, is certainly 10 if not 15 feet, being enough to throw the conglomerate entirely out of sight. If the throw were to the north it would need to be 25, and more probably 50, feet to do this.

The fact that the melaphyr under Crescent Hill, although rising to the west, can not be found, not even the slightest trace of it, on Great Hill, is alone sufficient to prove an important north-south fault between the two hills, with the downthrow to the east; and the further fact that not one of the dikes in Great Hill can be traced in Crescent Hill points to the same conclusion. Indeed, the contrast presented by the opposite walls of this narrow defile is one of the especially surprising and puzzling features of Nantasket geology. The very abrupt way in which the conglomerate of Crescent Hill terminates on the east proves that the hill is bounded in this direction also by an important north-south fault, the downthrow probably being as before on the side of Crescent Hill, or to the west.

Marsh Island is a large ledge of conglomerate and melaphyr completely isolated by the eastern marsh. Geologically it is but a repetition, at a lower level and without important displacements, of Crescent Hill. The conglomerate, which forms

the main mass of the ledge, is of the coarse, irregular type seen in Crescent Hill and on the east shore of the bay, containing many large pebbles of granite, felsite and melaphyr. The breadth of the conglomerate outcrop, from northwest to southeast, is about 140 feet; and the thickness of the bed, the upper and lower surfaces of which are clearly exposed, is about 25 or 30 feet. It is underlain on the northwest, at the very base of the ledge, by a highly scoriaceous and amygdaloidal green melaphyr, of which only a slight thickness is exposed; and is overlain on the southeast by a very similar flow of melaphyr, which at one point reaches up over the conglomerate nearly to the top of the ledge. These are undoubtedly true effusive contacts, and the upper one especially shows the dip of the conglomerate to be S. E. 10°—20°. The melaphyr contains abundant segregations and veins of epidote and red jasper. Since there appears to be no reason whatever to question the stratigraphic equivalence of Crescent Hill and Marsh Island, it is necessary to suppose that the marsh between them conceals an important fault; the downthrow being to the north and fully equal to the combined thickness of the conglomerate and upper melaphyr, about 50 or 60 feet.

FIG. 8.—GENERAL SECTION ALONG THE EAST SIDE OF THE RAILROAD. SCALE, 1 INCH = 300 FEET.

The foregoing details, which are summarized in the north-south section (Fig. 8), show that the various stratigraphic

features of this belt of ledges are readily explained by one bed of conglomerate between two very similar flows of melaphyr, with only such dislocations as are actually seen or may be reasonably inferred, until we come to the conglomerate underlying the lower melaphyr south of dike 25. This is a partial exposure only of a lower and older conglomerate which does not appear elsewhere in the section.

Although the transverse faults of this block are frequently reversed in throw and compensating, the northerly throw clearly prevails, the sum of all the displacements giving 161 feet to the north and 71 feet to the south. Hence the entire series is equal to one northerly slip of 90 feet.

Melaphyr Plateau.—This rectangular block of melaphyr is sharply defined by the bounding fault lines and escarpments, and may be regarded as a very characteristic feature in Nantasket geology. With the exception of the small patch of conglomerate on the western edge, it consists throughout of the most typical, basic, green variety of melaphyr, with frequent highly amygdaloidal layers. The flow-structure is very perfect at many points, and shows that the sheets or flows are still nearly horizontal, with slight undulations to north and south and, perhaps, a very gentle general dip to the southeast. The facts already stated in connection with the mass of conglomerate projecting into the western edge of the plateau indicate that the plateau embraces both of the flows of melaphyr observed in the Crescent Hill section. The lower flow forms the northern border of the plateau, or that portion north of the conglomerate extension; while all the remaining area, or fully three-fourths of the whole, must be referred to the upper melaphyr. The conglomerate, which normally separates the two flows, has been entirely cut out of the section, so far as the surface development is concerned, by the oblique strike faults. At the extreme eastern end of the plateau there are indications, in the form of thin outliers of sandstone, that the upper melaphyr was also formerly covered by conglomerate. It will appear later that this

conglomerate overlying the upper melaphyr should not be correlated with that forming the adjacent ledges of Conglomerate Plateau, but rather with that outcropping on Long Beach Rock and underlying the melaphyr series of Atlantic Hill.

Conglomerate Plateau.—This broad mass of conglomerate, the largest in the Nantasket district, is of the normal type, well rounded pebbles of felsite and granite predominating, although pebbles of porphyrite and compact melaphyr are also common. The texture varies from moderately coarse conglomerate to sandstone; but the bedding can be made out at only a few points as on the north side of Spring Valley Road. The dip seems, however, to be always gentle (5°—10°) to the south-southeast, diminishing toward the granite. The prominent ledges exhibit some well developed joint-planes; and the plateau is undoubtedly bounded on all sides, and not alone on the north, by fault-lines. It rises abruptly from the marsh on the west; Hull Street and Spring Valley Road traverse it in narrow defiles; while the straight and solid wall of conglomerate 15 to 30 feet high in which it terminates on the south is an exceptionally typical fault scarp. Facts will be presented later tending to show that the downthrow in the case of all of these faults is on the side away from the plateau, and hence that this conglomerate is older than and normally underlies the surrounding formations; but, as already indicated, the displacement is much greater on the north side than in any other direction. Of the thickness of the conglomerate it is impossible to speak with certainty, since neither the base nor, probably, the original summit of the bed are exposed. It can not be less than the height of the plateau, about fifty feet, and may exceed one hundred feet, this being, probably, the thickest of all the Nantasket beds.

Round Hill.—This hill, which, as the map indicates, is named for its curved outline, is a solid mass of conglomerate rising very abruptly from the eastern marsh on the north and west to to a height of fifty feet and sloping gently down to the south-

east beneath a bed of melaphyr. The conglomerate of Round Hill is connected with that of the plateau by essentially continuous outcrops along the eastern border of the marsh, and must be regarded as a part of the same bed. It is of medium texture above, passing in the lower part of the hill into fine conglomerate and a considerable thickness (10 to 20 feet) of reddish sandstone; while in the ledges rising from the marsh on the southwest we have a coarse and irregular conglomerate with layers of sandstone, which show that in these outlying ledges as well as in the hill the dip is mainly to the east or east-southeast and very gentle —5° to 10°, but rarely exceeding 5°. The exposed thickness of the conglomerate, including the outlying ledges, is probably between 75 and 100 feet. The low ledge of melaphyr protruding from the marsh on the north side of the hill is probably a part of the bed underlying the marsh; and the fault separating this melaphyr from the conglomerate is thus given a general east-west course. Since both this fault and that bounding the marsh on the east cut across the strike of the conglomerate, the breadth of the outcrop of that rock, as the map shows, has been greatly diminished at this southeast angle of the marsh where the fault-lines meet. According to the view here presented, the melaphyr forming the floor of the marsh belongs to the same bed as that overlying the conglomerate, and hence the conglomerate must also underlie the marsh, but at a greater depth than the melaphyr. More probably, however, as the isolated ledge of conglomerate in the channel east of Marsh Island suggests, the entire section of Marsh Island and Crescent Hill is represented beneath the marsh, the latter being bounded by faults on all sides and separated from Round Hill by a slip of at least 150 feet.

South of the hill, on the bank of the river (Lyford's Liking), the granite is well exposed, with conglomerate and sandstone resting against and upon it. The sandstone is really a fine, reddish and intensely hard quartzite; and both it and the conglomerate appear to fill fissures and depressions in the surface of the granite, in the same manner as the basal conglomerate of the

western area to be described later. If we make this correlation, then, since it is reasonably certain that other beds of melaphyr as well as conglomerate underlie the conglomerate of Round Hill, and we can not connect the latter with the basal conglomerate on the granite; it appears necessary to suppose that an important fault, with the downthrow to the north, separates the granite from the hill,—a continuation with a different direction of the fault extending from Granite Point on Weir River Bay southeasterly across Great Hill.

The melaphyr on the southeast side of Round Hill is nowhere seen in satisfactory contact with the conglomerate; but the slope of the hill on this side is nearly parallel with the bedding of the conglomerate, and all the indications are favorable to the view that the melaphyr overlies the conglomerate conformably. This is the typical green and amygdaloidal melaphyr of the central area, and cannot be distinguished from that outcropping in the marsh. The flow-lines dip gently to the southeast, as do the bedding lines of the conglomerate. To the north, this bed of melaphyr approaches very near the southeast corner of the marsh, as already explained; and we here reach the turning point of a marked and rather abrupt change in the strike of both the conglomerate and melaphyr. The normal dip of the Round Hill beds appears to be about east-southeast, and of the strata of Conglomerate Plateau and the district directly south of it, about south-southeast.

The District between Round Hill and Hull Street. This tract consists of rocky fields sloping southward from the escarpment marking the southern border of Conglomerate Plateau to the marshes of Lyford's Liking. The melaphyr overlying the conglomerate on the southeast slope of Round Hill bends to the east, as already explained, to follow the southern border of Conglomerate Plateau. Dikes 40 and 41 are evidently attended by some faulting; and the narrow band of conglomerate in the melaphyr may be accounted for in this way; but whether it belongs to the conglomerate below the melaphyr

or to that above it is not quite clear. The conglomerate south and east of the melaphyr undoubtedly overlies it, although there are no satisfactory exposures of the contact. The limited mass of melaphyr between the conglomerate and the granite, although possibly not *in situ*, is probably a reappearance of the melaphyr separating the two beds of conglomerate. It is topographically below the upper conglomerate. An important east-west fault, a continuation of the great border fault already referred to, must separate the conglomerate and melaphyr from the adjoining ledges of granite; and the latter here exhibit no traces of the basal conglomerate. The rather abrupt northward jog of the granite border may be explained by a southward extension with a slight displacement of the fault between Conglomerate Plateau and the marsh, as shown on the map. Farther east the melaphyr rises and broadens out, the overlying conglomerate having been carried above the present plane of erosion; and the underlying conglomerate fails to outcrop along the southern base of Conglomerate Plateau. In fact indications are not wanting that the melaphyr here covers the entire area between the plateau and the marsh. This would be readily explained without increasing the thickness of the melaphyr by simply regarding the beds as horizontal here; and the assumption is fully justified, even though the contact of the melaphyr and conglomerate can not be seen, by the fact that the flow-structure is well-marked in this melaphyr and quite horizontal.

The district between Hull Street and Strait's Pond.—This area is separated from the last by the fault, probably of no great magnitude, terminating Conglomerate Plateau on the east. It is topographically similar, and composed, apparently, of the same conglomerate and melaphyr, although extending north to the great east-west fault and the melaphyr of Centre Hill. The chief point of difference is found in the frequent alternations of conglomerate and melaphyr. These alternations are best explained by repeated east-west faults, dividing the district into seven or eight narrow blocks, as shown on the map. No satis-

factory contacts have been observed; but the ledges are so related as to indicate that the contacts must mark faults in most cases at least. The melaphyr is similar to that west of Hull Street; and the conglomerate is probably that underlying the melaphyr,– the conglomerate of Round Hill and Conglomerate Plateau; although it would be difficult to prove that the overlying conglomerate is not also represented here. Dike 31, the only one observed in this district, separates conglomerate and melaphyr and is unquestionably a fault-plane. On the south, near the Hull Street bridge, the granite outcrops boldly, with no traces of conglomerate or melaphyr upon it. The melaphyr outcrops very near the granite on the north; but, although the contact is not exposed, it seems impossible to doubt that a fault divides them here, as at points farther west. Folsom's Island probably lies on the farther side of a moderate north-south fault, which terminates these narrow fault-blocks and defines the abrupt eastern face of Centre Hill. There seems to be no reason to doubt that this is the conglomerate underlying the melaphyr; and since a careful search has failed to discover any melaphyr here, we may fairly suppose that it is unbroken by east-west faults, that the bedding planes are essentially horizontal, and that it has been elevated sufficiently by the north-south fault just referred to to carry the melaphyr wholly above the present plane of erosion. Crossing Strait's Pond at this narrowest point, we find what appears to be the same conglomerate outcropping abundantly between the pond and Jerusalem Road. It extends quite up to the street, and immediately opposite are the ledges of granite. The beds strike about northwest and dip northeast 30° to 40°. It is plain that the conglomerate runs diagonally against the wall of granite, from which it must be separated by a fault. The conglomerate probably forms the whole of this rectangular area north of Jerusalem Road and it actually outcrops again at the extreme eastern end, where the small promontory projects eastward into the pond. In fact, when we consider in this connection the straightness of the granite border and the important development of conglomerate at the base of Green Hill, it appears at least

probable that almost the entire basin of Strait's Pond is underlain by this conglomerate. It is this view of the geological stucture that is intended to be expressed in the arrangement of the fault-lines on the map. Of course, if the conglomerate is carried down to any considerable depth by the rather high dip which it shows near Jerusalem Road, it is very probably covered in the central part of the basin by the overlying melaphyr.

The Western Area.

This area comprises all that part of Nantasket proper west of the railroad. It is bounded on the south and west by Weir River Bay, and on the north by Nantasket Harbor. We have already met the fundamental granite along the southern margins of the central and coastal areas; but it is in the western area that we first encounter what appear to be the oldest beds of conglomerate and melaphyr in the Nantasket district. The geological structure is quite as varied and complex as in the central area, and as before, the descriptions may most conveniently follow the topographic order.

Granite Plateau.— This is the name given to the largest mass of granite in the Nantasket peninsula. It forms the large southwestern angle of the western area, and is a compact group of ledges having, for the most part, an elevation of from twenty to forty feet. The granite is of the normal type, and, exhibiting but slight variations, requires no special description; but the outliers of conglomerate scattered over the plateau are a feature of particular interest. The more important of these are indicated on the map; and the best and clearest exposures are, naturally, to be found along the shore. The conglomerate is most abundant around the northeast corner of the plateau, where it shows east and southeast dips of 5°—10°, and a maximum thickness of perhaps 15 feet. Elsewhere it is hardly thick enough to conceal the granite; and everywhere it is largely composed of angular and unassorted débris of precisely the same granite. This is

SECTION OF AN IRREGULAR FISSURE IN THE SURFACE OF GRANITE PLATEAU FILLED WITH CONGLOMERATE. SCALE, ONE FIFTH NATURAL SIZE.

PLAN OF FISSURES IN THE SURFACE OF GRANITE PLATEAU FILLED WITH SANDSTONE AND FINE CONGLOMERATE. SCALE, ONE FIFTH NATURAL SIZE.

alone sufficient to prove that the conglomerate is newer than, and was deposited upon the granite; although at first glance, or in a general view, the opposite relation might be regarded as well sustained, the conglomerate appearing as isolated masses enclosed in the granite. But an examination of the contact between the two rocks removes all doubt as to the true history of Granite Plateau. The conglomerate clearly rests upon the granite and fills the irregularities of its surface. Instead of the granite being intrusive in the conglomerate, the appearances are just the reverse, narrow cracks in the granite being filled, dike-like, with conglomerate and sandstone. These fragmental dikes, the roots of a once continuous bed of conglomerate, are exposed repeatedly along the shore, as well as over the surface of the plateau; and they seem to prove conclusively that erosion has cut just to the base of the conglomerate, clearly exposing the original granite floor, but leaving it essentially intact. It is very evident that the conglomerate was deposited over such a broken and fissured surface as the granite presents along our shore to-day.

Besides the granitic débris, the conglomerate includes numerous pebbles of felsite and a large proportion of melaphyr, showing that volcanic action had been instituted in this region before the formation of this bed of conglomerate and hence that, although resting directly upon the granite, it is not the true basal conglomerate. Probably, as a rule, each successive bed reached farther inland, the overlapping edges, only, being in immediate contact with the granite. The conglomerate in the more southern outlier on the eastern edge of Granite Plateau is curiously involved with irregular masses of a compact eruptive rock, which can not be referred directly to either an underlying or overlying mass of lava but which proves on examination to be identical, lithologically, with the first flow to be described in other parts of the western area. The significance of its occurrence at this point will be explained after we have studied the flow to which it is related.

The granitic area south and southeast of the west marsh,

embracing the isolated ledges of granite in the marsh and the southern slope of Great Hill, is essentially similar in every respect, including the outliers of conglomerate; but the intervening marsh is probably underlain wholly by conglomerate, which has been depressed by faulting. The principal exposures of conglomerate are on the borders of the marsh, directly south of Great Hill, where it is seen almost in contact with but not directly upon the granite, dipping away from the latter or southeast 5° to 10°. The outlying mass near the bank of the river is almost certainly *in situ*, and indicates that a considerable body of conglomerate is concealed here. Traces of conglomerate have been observed on the outlying ledge of granite in Weir River Bay; and the preceding description might be repeated for Granite Point, although it is separated from the plateau by the boundary fault, which, with the downthrow to the north, marks the northern limit of the granite at most points.

Granite Point is a knob of granite capped with conglomerate dipping slightly to the east and northeast, the beginning of an important bed extending into Cliff Plateau. The relations of the granite and conglomerate are especially clear on the south side of the point (Fig 9). A large and irregular hollow or ravine in the granite is filled with conglomerate largely composed of granite débris and including several large bowlders of granite, each of which is precisely similar in character to the nearest part of the enclosing granite. This conglomerate is from one-half to two-thirds melaphyr, often in large and angular fragments. Although this is so clearly not the basal conglomerate of the Boston Basin, it will appear in the sequel that it is probably the lowest bed now exposed in any of the Nantasket sections; and it will, for convenience, be designated hereafter the first or basal conglomerate. It is interesting mineralogically on account of the numerous segregations of bright red jasper which occur in it. These are exceedingly irregular in outline, apparently replacing the paste of the conglomerate. The origin of the jasper is, doubtless, to be found in the alteration of the melaphyr; and attention has already been called to the prob-

able fact that the intense hardness of the Nantasket conglomerates is due to interstitial silica derived from the same source.

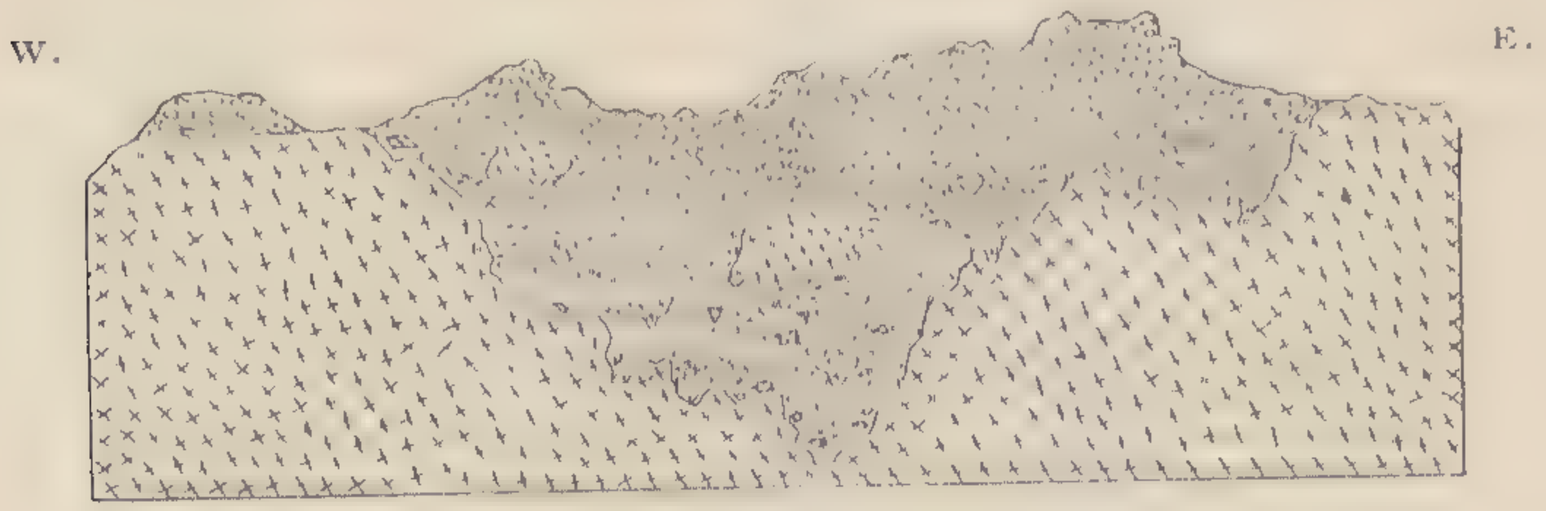


FIG 9.—SECTION OF THE GRANITE AND OVERLYING CONGLOMERATE ON GRANITE POINT.
SCALE, 1 INCH =10 FEET.

Cliff Plateau.—Cliff Plateau comprises the triangular group of conglomerate and melaphyr ledges between Granite Plateau and the shore on the north. The average elevation is about thirty feet, but two points rise above fifty feet. The name refers to the well-marked cliff 25 to 40 feet high which bounds it on the north, extending from Granite Point to dike 66. Granite Point, as already stated, is overlain by the basal conglomerate, with thin beds of sandstone showing nearly horizontal dips, the main slope being to the northeast. One bed of sandstone two to three feet thick runs the entire length of the cliff facing West Porphyrite Hill, until it meets dike 33, meeting it about five feet above the beach and thus sloping approximately one foot in ten. It is thrown up about three feet by this dike and then continues with the same inclination, but growing less distinct, to dike 31, beyond which it cannot be traced, probably passing under the water. The eastern half of the cliff, rising abruptly from Nantasket Harbor, between dikes 33 and 66, is composed entirely of this conglomerate, with the exception of a narrow slice of the overlying melaphyr which, toward the eastern end, has been let down by a fault trending N. 80° E. with the downthrow to the north. In fact, as the map shows, the basal conglomerate forms throughout the main body of the

plateau, having for the greater part of the area a southeasterly dip of 5°—10°. It is overlain on the east and southeast by two considerable patches of melaphyr, detached areas of what must originally have been a continuous flow. This melaphyr is a greenish to purplish, compact or finely crystalline, non-amygdaloidal variety, containing epidote in minute crystallizations and also larger segregations of both epidote and red jasper. It is distinctly different from, and undoubtedly older than, any melaphyr in the Central or Coastal areas, although bearing some resemblance to the more basic porphyrites.

The contact between the basal conglomerate and the southeastern patch of melaphyr is very clearly exposed, especially on the west side of the melaphyr, and the melaphyr unquestionably overlies the conglomerate. The contact appears on the map as a regular curve convex to the northwest, indicating that the melaphyr lies in a shallow trough. This appearance is due partly, however, to the very plain east-west fault which marks the northern edge of the melaphyr, with a downthrow to the south of, perhaps, ten feet. The melaphyr is distinctly and comformably overlain on the southeast by two small patches of what must be a second bed of conglomerate, since the melaphyr separates it from the basal conglomerate. These outlines owe their preservation chiefly to the two east-west faults shown on the map and downthrowing to the south ten and fifteen feet, approximately. The boundary fault separating these rocks from Granite Plateau is an absolute necessity at this point; for their nearly level beds are *vis-a-vis* with the abrupt ledges of granite. The displacement here cannot be less than twenty-five nor, probably, more than fifty feet; for the basal conglomerate, which caps the granite on the south side of the fault, is at least forty and possibly fifty feet thick, and the overlying melaphyr is twenty-five to thirty feet.

The northern area of melaphyr appears also to occupy a shallow trough, and the intervening portion of the basal conglomerate must be slightly anticlinal in structure; although the ridge coinciding with dikes 22 and 34, and slightly capped with

melaphyr at one point, rises so abruptly from beneath the melaphyr on the north as to suggest an intervening fault, which is indicated on the map, with the downthrow to the north. Layers of sandstone in the eastern end of this ridge show the usual easterly dip. The contact between the basal conglomerate and this northern patch of melaphyr is clearly exposed along the brink of the cliff and in the gorge formed by dikes 66, where the dip is southeast perhaps 10°; and it can be traced quite around the west end of the melaphyr, which everywhere plainly overlies the conglomerate. The northern patch of melaphyr, like the southern, is overlain on the southeast by a thin cap of the second conglomerate, this upper contact being parallel with the lower. The normal succession of all the rocks in Cliff Plateau is clearly exhibited in the accompanying section.

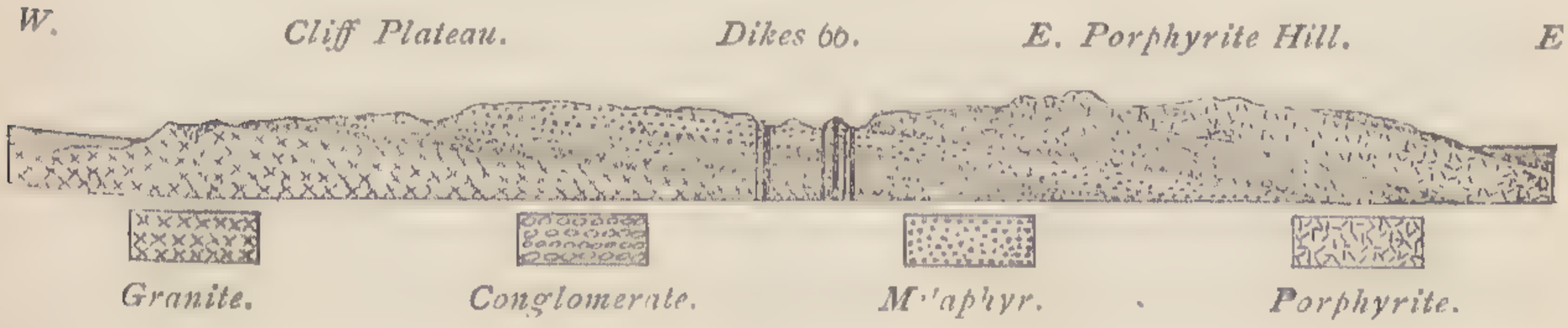


FIG. 10.—SECTION FROM GRANITE POINT ACROSS CLIFF PLATEAU AND EAST PORPHYRITE HILL. SCALE, 1 INCH = 400 FEET.

East Porphyrite Hill. — This hill, which forms the prominent northeast angle of the western area, is separated from Cliff Plateau by the group of north-south dikes (66) and the depression or gorge due to their erosion. It is surprising to find that these repeated fractures are accompanied by no appreciable displacement; but the basal conglomerate, the melaphyr, and the second or overlying conglomerate can all be traced across the dikes without the least slip (Fig. 10). The basal conglomerate just barely shows at the base of the cliff on the east side of the dikes and does not reappear beyond, the easterly slope of all the beds being very noticeable. The melaphyr can be followed

along the shore as far as dike 27, when it also disappears, and the second conglomerate becomes the prevailing rock on the west side of the hill. This conglomerate, which is largely a fine-grained grit and sandstone, and hence plainly stratified, is characterized by segregations of red jasper, but in a less degree than the basal conglomerate. The dips are rather high, E. about 20° on the west side of the hill and S. E. 27° near the overlying porphyrite at the north base of the hill. The conglomerate is conformably overlain by the great mass of porphyrite which forms the summit and eastern and southern slopes of the hill, the actual contact being particularly well-exposed on the north side. As a whole this porphyrite is similar to that of the Coastal area, but it is rather more felsitic in texture, redder in color, non-epidotic; and segregations of red jasper occur in it to a limited extent. The base of the flow is mainly of a greenish gray color changing upward to a dull reddish tint; and the upper part is largely of a deep dull red, often resembling at a little distance a dark red sandstone. Near the contact with the underlying conglomerate it shows a distinct flow-structure, parallel with the contact, as well as a coarse and fine brecciation, the latter resembling or passing into a genuine "toadstone" or spherulitic structure. Dike 27, which crosses the hill approximately at right angles to the strike, is accompanied by an important fault. It downthrows to the north and shifts the contact of the conglomerate and porphyrite about 175 feet, as shown on the map, equivalent to a vertical slip of fully 50 feet. This hill is a complex of dikes, and since all, apparently, are attended by some displacement, the continuity of the contact between the conglomerate and porphyrite is lost. This confusion makes it difficult, also, to determine the exact thickness of both the porphyrite and conglomerate. It is quite certain, however, that the entire thickness of the porphyrite, as well as of the conglomerate, is exposed here; for it is undoubtedly overlain conformably by the small patches of conglomerate on the southeast corner of the hill (Fig. 10).

These patches must belong to a third bed of conglomerate, and since they are parallel with the second or underlying conglomerate, the separation of the two beds measures, approximately, the thickness of the porphyrite, which cannot well be less than fifty feet and may be more. I have, however, observed no distinct indications that it is a composite flow; but it is from bottom to top one solid and essentially homogeneous mass. The underlying conglomerate must be nearly as thick as the porphyrite.

West Porphyrite Hill.—This approximately isolated and well-defined rock-mass is, in both form and structure, an almost exact repetition of East Porphyrite Hill, except that the structure is but slightly complicated by faults and dikes. In short it is a solid bed of conglomerate underlain by melaphyr and overlain by porphyrite; and none of the Nantasket ledges present a clearer or more instructive section (Fig. 11). The underlying melaphyr is very compact for the most part, greenish and purplish, non-amygdaloidal, and not conspicuously brecciated or scoriaceous, except near the original surface of the flow, where it is in contact with the conglomerate. It shows many minute crystallizations and some whitish veinlets of epidote, and numerous small, irregular segregations of bright red jasper. In other words, it is essentially identical with the melaphyr which we have found overlying the basal conglomerate on Cliff Plateau and passing beneath the second conglomerate on East Porphyrite Hill. The outcrop begins on the north at the end of the beach leading to Melaphyr Peninsula and skirts the base of the hill to the middle of the west end. The contact with the overlying conglomerate is exposed continuously for several hundred feet, but the base of the melaphyr is not seen, the thickness exposed in the hill not exceeding 15 feet. A greater thickness is proved, however, by the outlying half-tide ledges, which extend nearly half-way across Weir River Bay. These were carefully examined; and all that are marked

as melaphyr on the map are of precisely the same kind as that just described, and are plainly parts of that flow. The tops of the ledges sometimes show traces of the overlying conglomerate; and these prove a very perceptible westerly dip, as if the bay occupied here a faintly marked syncline.

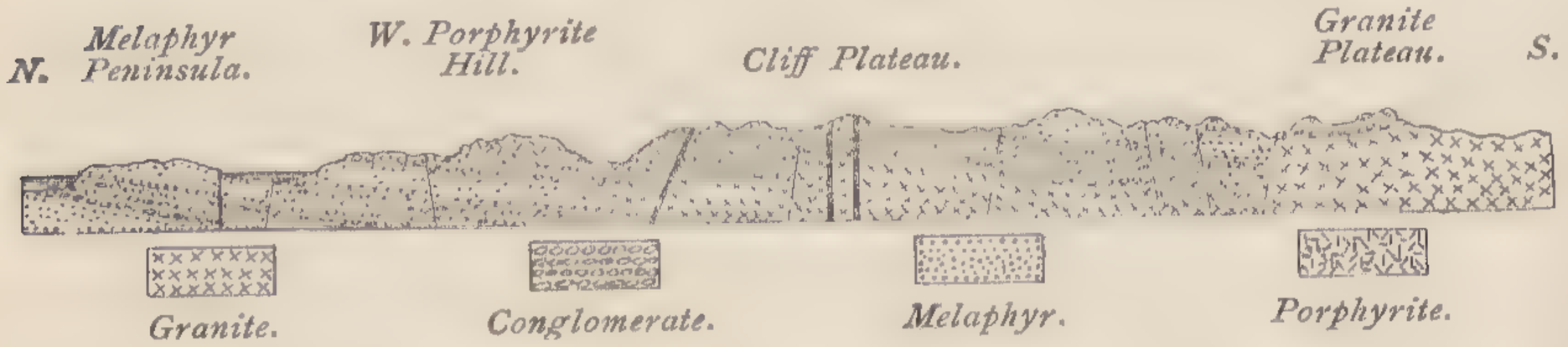


FIG. 11.—SECTION FROM NANTASKET HARBOR ACROSS MELAPHYR PENINSULA, WEST PORPHYRITE HILL, AND CLIFF PLATEAU TO GRANITE PLATEAU. SCALE, 1 INCH = 400 FEET. THE DIKES ARE, FROM NORTH TO SOUTH, NOS. 28, 31, 34, AND 22. DIKE NO. 29 IS OMITTED.

The conglomerate is mainly of medium texture, and becomes finer upward; but at the base it is in a large part very coarse and irregular. The contact with the melaphyr, although so perfectly exposed, is somewhat obscure and indefinite, because the conglomerate fills the numerous cracks and marked inequalities which naturally characterize the upper surface of the melaphyr flow; and also because at its base the conglomerate is largely, in some cases almost wholly, composed of melaphyr debris. Very few of the fragments and pebbles of melaphyr are amygdaloidal; and they can nearly all be certainly referred to the subjacent bed. Near the base of the conglomerate, especially, many of the component fragments are exactly like the melaphyr which it rests upon. It would, perhaps, be difficult to find a clearer example of a contemporaneous lava covered by newer sediments. The relations of the two rocks are simply inexplicable on the theory that the melaphyr is intrusive. Along the contact, especially, granite is very abundant in the conglomerate; and several masses were noticed from one to three feet in diameter, the largest ones resting directly upon the melaphyr, or seeming to be almost imbedded in it. The

granite is chiefly rounded, but some blocks, like many of the melaphyr fragments, are rather angular. The segregations of red jasper occur in all parts of the conglomerate, but most abundantly in the lower part. In none of the Nantasket rocks is it more plentiful or more favorably exposed for observation. Intercalated layers of sandstone show that the conglomerate is nearly horizontal, but undulating, along the north side of the hill; while around the western end the contact with the melaphyr, and the strings of sandstone, dip gently (5°–10°) to the east. The true thickness of the conglomerate is probably not over 25 feet and almost certainly less than the same bed on East Porphyrite Hill. The outlying ledge of conglomerate west of Granite Point, instead of belonging to the basal conglomerate, as one might have judged from its position, is precisely like the conglomerate of West Porphyrite Hill, being coarse and largely made up of the underlying melaphyr, and containing numerous large fragments of granite, etc. The channel between this conglomerate and the ledges of melaphyr north of it probably marks a slight fault (10 to 20 feet) with the downthrow to the south.

The overlying porphyrite, of which about 25 feet in thickness still remain, is very similar to the lower half of that on East Porphyrite Hill. It is compact (felsitic), not distinctly crystalline, porphyritic or amygdaloidal, and quite homogeneous, except for the scattering and mostly small segregations of red jasper. The colors are chiefly pale green and red tints, weathering usually light pink. The absence of the dark red variety which is so prominent on East Porphyrite Hill is due to erosion, the entire upper half of the porphyrite having been removed from the western hill, while the eastern hill still shows a complete section of the flow. The porphyrite is seen near the conglomerate at several points on the north and west sides; but the only clear and satisfactory exposure of the actual contact is afforded by the rather precipitous eastern face of the hill. The contact here shows an exceptionally steep southerly dip

of about 25°; and this is still farther augmented by a fault with a downthrow to the south of perhaps ten feet, which skirts the northern edge of the porphyrite and crosses the level platform of conglomerate to the western base of the hill, as shown on the map, thus explaining the abrupt termination of the melaphyr midway of the breadth of the hill. Along the contact with the conglomerate the porphyrite, as on the eastern hill, is somewhat brecciated, and shows a distinct flow-structure parallel with the contact, as well as a coarse sort of spherulitic or concretionary structure. On the southwest corner of the hill the conglomerate is seen to pass beneath the porphyrite, but the contact is not clearly exposed. The southern face of the porphyrite is precipitous, matching the opposing face of Cliff Plateau; and there can be no reasonable doubt that this narrow pass marks an important fault with the downthrow to the north; for the porphyrite is *vis à vis* with the basal conglomerate, and the melaphyr exposed at the northwestern base of West Porphyrite Hill is the equivalent of that forming the southeastern summit of Cliff Plateau. The displacement must be equal to the combined thickness of the porphyrite and the underlying conglomerate and melaphyr, *i.e.*, all the beds in West Porphyrite Hill, or 75 feet as a minimum. This fault probably passes southwest between the outlying ledges of conglomerate on the north and granite on the south; and the boundary fault between Granite Plateau and Cliff Plateau, which certainly diminishes rapidly in this direction, appears to terminate on this line, as represented on the map.

We now have above the granite, in regular sequence, the following beds: (1) the first or basal conglomerate, on Granite Plateau, Granite Point, and Cliff Plateau; (2) the first melaphyr, on Cliff Plateau and East and West Porphyrite Hills; (3) the second conglomerate, on Cliff Plateau and East and West Porphyrite Hills; (4) the porphyrite, on the Porphyrite Hills; and (5) the third conglomerate, on the southeast corner of East Porphyrite Hill. From Granite Point to

the bay east of East Porphyrite Hill the section is continuous and complete, all five of the beds being represented (Fig. 10); but the evidence along this line is greatly strengthened at the weakest point by the very clear and simple section afforded by West Porphyrite Hill (Fig. 11). The lithological comparisons are almost perfect and certainly safe for so small an area; and the succession may be said to rest at every step on the approved canons of stratigraphy.

The general structural relations of the rocks in those portions of the western area already described are clearly exhibited in the two accompanying sections: one (Fig. 10) east and west, and the other (Fig. 11) north and south. For the sake of greater clearness the east-west dikes are not shown in the first section.

Conglomerate Hill.—This completely isolated mass of conglomerate is, perhaps, the simplest of all the structural blocks composing the Nantasket area. It is all conglomerate, with the exception of occasional thin layers of hard red sandstone, which show a dip of not more than from 5° to 10° to the east or a little south of east. Some parts of the conglomerate are very coarse, holding pebbles from six to twelve inches in diameter; while other parts are very fine and arenaceous. The red jaspery porphyrite of East Porphyrite Hill is a very conspicuous constituent; but the red jasper is also, to a very limited extent, an indigenous constituent, forming irregular segregations in the cement of the conglomerate. The hill appears to be entirely unbroken by either faults or dikes; and the most diligent search has failed to reveal a vestige of eruptive rock of any kind, except in the form of pebbles. There are no overlying rocks; and the base of the conglomerate is not exposed. Hence the total thickness of this bed is a matter of conjecture; but since the eastern slope of the hill is approximately parallel with the dip, the exposed thickness must be at least fifty feet. The hill is surrounded on all sides by grass land and marsh;

and about the only clue to its stratigraphic position is that afforded by the enclosed pebbles of jaspery porphyrite. There can be little or no doubt that these represent the flow on East Porphyrite Hill; and the inference appears to be justified that this is the third conglomerate, a small outlier of which has already been observed resting upon the porphyrite. This view of its position means that Conglomerate and East Porphyrite Hills are separated by an east-west fault with a downthrow on the south of fully fifty feet. Following this fault west to the valley between these hills and Cliff Plateau, we find that it must terminate in a north-south fault, for it cannot be traced across the plateau; and this transverse fault must downthrow to the east, for otherwise there would be insufficient room beneath Conglomerate Hill for the porphyrite and the second conglomerate. Conglomerate Hill thus appears as a rectangular block which has dropped down, the downthrow being greatest at the junction of the two faults, at the northwest corner, which explains the fact that the dip is less than in East Porphyrite Hill and more easterly. The north-south fault probably coincides with dikes 66 and extends with greatly diminished throw nearly or quite to the north shore, terminating all the minor faults crossing Cliff Plateau. East Porphyrite Hill and Cliff Plateau are thus two broken fault blocks which have risen relatively to Conglomerate and West Porphyrite Hills; while all these blocks must have dropped with reference to Granite Plateau.

Great Hill.—This is the highest point in the western area, rising very abruptly 74 feet above the western marsh, and it is the boldest and most impressive topographic feature in all Nantasket. With the exception of the granite which supports the hill on the southwest, it is another isolated mass of conglomerate; and we are obliged to depend wholly upon internal evidence in determining its stratigraphic relations. The entire lack of correspondence between Great and Crescent Hills has

already been cited as proving a displacement between them; and the same reasoning applies with equal force when we pass from Great Hill to Conglomerate Hill. The Great Hill conglomerate is extremely irregular, varying abruptly and repeatedly from fine sandstone to a mass of granite and melaphyr bowlders one to three feet in diameter. Granite pebbles and bowlders are numerous, but usually rounded. Felsite and melaphyr are also abundant, but the latter is never amygdaloidal. The conglomerate is jaspery at most points—red jasper, but so highly ferruginous as to be perceptibly less bright and hard than that in the more western hills. It occurs, however, in the same way, and lends support to the view that this conglomerate should be correlated with one of the three lower or basal beds. The conglomerate is thoroughly indurated throughout, although this is most noticeable in the sandstone layers, which are as hard as quartzite, but always red, felsite debris largely predominating. The dip is flat as a whole, but variable,—horizontal at some points and inclined 15°–20° at others, especially near the granite. The normal dip appears to be east to southeast and not above 5°; and the exposed thickness of the conglomerate must be nearly the height of the hill or at least sixty feet.

There is no overlying and there appeared at first to be no underlying melaphyr or porphyrite; and the exact correlation of this conglomerate seemed a hopeless task, until I came to study in detail the phenomena presented near the contact with the granite, on the southwest corner of the hill. It is evident at a glance that the main body of conglomerate does not rest upon the granite, but is faulted down against it, the boundary fault crossing the hill at this point, and with essentially the same result as on the west side of the marsh. The granite is, however, capped by several feet of conglomerate at this point; and the fault, which is very clearly exposed, hades irregularly to the north. Following it down carefully we come finally, some six feet below the top of the granite and about fifteen

feet above the marsh, to the base of the conglomerate. It is seen to rest upon a compact greenish and purplish eruptive rock, which proves to be identical with the first melaphyr of Cliff Plateau and West Porphyrite Hill. It can be traced northward about one hundred feet, the contact gradually sloping down to the level of the marsh. Its contact with the granite is clearly a fault with the hade and throw to the north, and considerable fragments of the melaphyr appear to lie along the fault-fracture above the base of the conglomerate, testifying further to the direction of the slip. In short, we have exposed at this point, on the south side of the fault, the granite capped by conglomerate; and several feet below this contact, on the north side, the first melaphyr overlain by the main body of conglomerate forming Great Hill. The conglomerate on the south is probably the first or basal bed, as indicated by its relations to the granite; and that on the north must be the second bed, as proved by its relations to the melaphyr. This makes the displacement equal to the combined thickness of the basal conglomerate and the first melaphyr, perhaps 75 feet in all.

It is a fact, however, that the fault-fracture cannot be traced upward *through* the conglomerate; but the conglomerate overlying the granite is essentially continuous with that north of the fault-line; and it would, perhaps, be best to refer all of the Great Hill conglomerate to the first or basal bed, regarding the underlying melaphyr as a lower flow than has been seen elsewhere in the western area. This view, which would dispense with the fault between the granite and conglomerate, derives further support from the fact that the basal conglomerate on Granite Plateau and elsewhere is crowded with the debris of similar melaphyr; but it is not followed in the construction of the map, simply to avoid multiplying lava-flows where the facts do not absolutely require it. Still another interpretation is consistent with all the observed facts; *viz.*, that the conglomerate belongs wholly to the second bed and that the sup-

posed fault is really an overlap, the conglomerate having covered a boss of granite which rose like an island through the first or underlying melaphyr.

Following the fault-contact across to the southeast corner of the hill, we again find the conglomerate on the north underlain by the compact melaphyr; and the granite outcrops at a little distance on the south without any capping of conglomerate, erosion having cut deeper here. It is evident now that Great Hill must be on the upthrow side of the fault bounding it on the northwest; and that the displacement is more than equal to the combined thickness of the porphyrite and third conglomerate, or more than 100 feet.

Correlation of the First Melaphyr. — Passing down the long southwestern slope of Great Hill, we come at last, in the ledges of granite isolated by the western marsh, to the large dike of melaphyr, No. 2 of the map and the descriptive list of dikes. This dike, which is strongly contrasted in character with all the diabase dikes of this district and certainly is not, as it appears to be at first glance, a southward continuation of the composite dike (66) separating Cliff Plateau and East Porphyrite Hill, demands our attention at this time on account of its important and interesting relations to the first melaphyr, the only melaphyr of the western area. The microscopic resemblance is certainly very marked, and in his brief description of the microscopic characters (page 37), Mr. Merrill has cited no fact inconsistent with the view that the dike is a more crystalline and less altered form of the same original rock as the flow. Attention was first attracted to this dike, as regards its relations to the effusive melaphyr, in seeking an explanation of the melaphyr which is mingled irregularly with the first or basal conglomerate on the eastern edge of Granite Plateau. This ledge of conglomerate and melaphyr is only a few feet west of the direct course of the dike; and the question naturally arose, Why may not these irregular intrusions be

regarded as branches from this dike? To actually trace the connection is impossible, on account of the marsh; but I have endeavored to show its probability by demonstrating more fully the identity of this melaphyr with the dike and also with the surface flow. To this end, characteristic specimens of melaphyr from—I. the flow at the base of West Porphyrite Hill, II. the flow at the base of Great Hill, III. the irregular intrusions in the basal conglomerate, and IV. the great dike, have been submitted to chemical analysis, through the kindness of Dr. T. M. Drown of the Massachusetts Institute of Technology. Four closely accordant determinations of the silica and of the iron oxide (Fe_2O_3) and alumina were made for each sample by the chemists of the class of 1892, with the following average results :—

	I	II	II	IV
SiO_2	47.97	51.05	47.29	54.47
$Al_2O_3 + Fe_2O_3$	30.50	30.16	30.20	25.25

Although these results, especially for the silica, do not agree so well as could be desired, the differences should not excite surprise, when we consider that, since these rocks are all highly altered, and filled with quartz, epidote, and other secondary minerals, it is well-nigh impossible to select average or normal specimens. Probably four specimens from the same mass (dike or flow) would show similar differences. Regarding, then, these different outcrops of melaphyr, of whatever form, as essentially identical in macroscopic, microscopic, and chemical characters, we may reasonably suppose that they are contemporaneous, and that the great dike is one of the vents at least, if not the only vent, through which the sheet of melaphyr overlying the basal conglomerate reached the surface. The fissure is straight and regular in the granite; but on passing into the then unconsolidated gravel of the basal conglomerate it naturally became very irregular, the melaphyr and gravel becoming inextricably mingled, as observed on the eastern edge

of Granite Plateau. The fact that we cannot trace this dike above the basal conglomerate is thus readily explained; for this conglomerate was then the surface deposit, the newest sediment upon the ocean floor. Taking all these features into consideration, it is doubtful if there can be found elsewhere in the Boston Basin so clear an exhibition of a complete eruption—complete in both its intrusive and extrusive phases.

Correlation of the Central and Western Areas.—Up to this point the stratigraphy of the western area presents no serious or insuperable difficulty, each group of ledges presenting certain recognizable features common to some of the others. But on attempting to extend this correlation to the central area the case is very different; for the break between Great and Crescent Hills, the only point where the two areas are in contact, is so profound that at first glance the two sections seem to have nothing in common. The peculiar first melaphyr and the porphyrite, which are the principal keys to the western area, are certainly wholly wanting in the central area. I have already stated that the heavy bed of conglomerate forming Conglomerate Plateau, Round Hill, and, probably, the ledges to the eastward as far as Conglomerate Island and Green Hill, should, apparently, be correlated with the conglomerate underlying the lower amygdaloidal melaphyr at the northern end of the section along the railroad. If this is done, then, while the western area consists, exclusive of the fundamental granite and Melaphyr Peninsula, of three beds of conglomerate and two intercalated flows of lava—one basic and one acid; the central area is made up of two beds of conglomerate, each of which is overlain by a flow of amygdaloidal melaphyr. The base of the lower and principal conglomerate is nowhere exposed; but I see no reason to doubt that it rests upon the porphyrite, and is the equivalent of the third conglomerate in the western area. This interpretation of the facts has the merit of simplicity, and it leaves no observed facts unexplained. The summit of the

western section becomes the base of the central section, the two together including four beds of conglomerate and four beds of lava.

Strictly speaking, the basal conglomerate is not wanting in the central area, since it is undoubtedly represented by the patches of clastic material on the granite south of Round Hill; and this hill thus admits of comparison with Great Hill. The relations to the granite and the boundary fault are the same; but the Round Hill conglomerate is the third bed and the Great Hill conglomerate is the second bed.

The satisfactory correlation of the central and coastal areas presents still greater difficulties, and appeared practically impossible, until, fortunately, a partial clue was afforded by the ledges on Rocky Neck. The completion of the Nantasket column must, therefore, await the detailed description of the Rocky Neck section; and it will suffice here to state that all the melaphyr of the coastal area and the underlying conglomerate of Long Beach Rock belong above the highest bed, the third melaphyr, in the central area.

Melaphyr Peninsula.—This most northerly and most nearly isolated part of the western area is the only part that does not admit of ready correlation without appealing to external evidence. For this reason, and because it is probably the newest part of the area, its description has been reserved to the last. Melaphyr Peninsula is quite certainly made up of two principal flows of highly basic and amygdaloidal melaphyr. The northern and older flow shows, at the west end, three fairly distinct bands of coarse amygdules, averaging about three feet thick. The lowest is near the water, and the second is separated from it by three feet and from the third by two feet of compact melaphyr. The exposed thickness of this flow is about 15 feet, and it is clear that we see only the superficial, vesicular part of it. Immediately east of the dike (67), the second and third bands of amygdules

are united; but farther east they diverge again and for a hundred feet or more are separated by from one to four feet of compact melaphyr. Beyond that they seem to unite; but other amygdaloidal bands appear below them, and toward the east end there are from three to five indistinct bands. These bands may, perhaps, be regarded as successive waves of lava, and essentially parts of one flow. At many points the amygdules are arranged in distinct sheets or lines parallel with the main bands, giving rise to a very beautiful flow-structure, and in none of the Nantasket ledges is the flow-structure more perfectly developed than here. Both the lines and bands dip S. 5°–10°, the strike being N. 80° E.

The amygdules range from pin-heads to one inch in diameter, and average fully one fourth inch. They are chiefly composed in order of importance of: (1) whitish, compact epidote (mixed feldspar and epidote); (2) quartz; (3) feldspar, which is often reddish; (4) chlorite; and (5) bright green epidote. The compact, whitish epidote also forms many irregular veinlets, which conform with the flow-structure, or cut it at all angles, and pass insensibly into the large amygdules. In all these segregations, the quartz was the last mineral to be deposited. Quartz has not been observed in the same amygdules with chlorite, but feldspar, epidote, and quartz were always deposited in that order. The sequence of the minerals in the amygdules is quite varied and the following, stated in the order of abundance and beginning on the outside in every case, have been observed: (1) mixed feldspar and epidote, and quartz; (2) feldspar and quartz; (3) feldspar, epidote, and quartz; (4) epidote and quartz; and (5) mixed epidote and feldspar, and chlorite. Occasionally bright red jasper occurs with the quartz. The amygdules were carefully examined to see if their elongation and orientation throw any light upon the direction of the flow. The smaller amygdules are mainly spherical; and the larger ones, although elongated, are usually very irregular. So far as the evidence goes, it favors the view that the lava came from the east.

The second flow of melaphyr begins with about fifteen feet of compact, green melaphyr overlain by five to ten feet, in one to several bands, of amygdaloidal melaphyr. It is similar to the first flow, except that the amygdules are not so crowded and the bands are not so well defined. These flows are strongly contrasted with, and undoubtedly much newer than, the flow forming the base of West Porphyrite Hill, one hundred feet away. The isolation of this outcrop makes an absolutely safe correlation impossible. It is reasonably certain, however, that it should be referred to either the upper or lower amygdaloidal melaphyr of the central area. It looks like a block detached from Melaphyr Plateau: in fact the lithological resemblance is almost perfect. And this view is strengthened by the low-tide ledges of precisely the same melaphyr which stretch away to the eastward, in the direction of Melaphyr Plateau, and virtually extend Melaphyr Peninsula as far as the base of East Porphyrite Hill. It is a foregone conclusion, then, that the short beach connecting Melaphyr Peninsula and West Porphyrite Hill conceals an important fault with the downthrow to the north, an extension, apparently, of the line of displacement dividing the coastal and central areas. The slip can scarcely be less than 150 feet, and may easily be 100 feet more.

Rocky Neck.

The part of Weir River Bay separating Rocky Neck from Nantasket is not a geological boundary; for the western shore repeats, with slight variations, the geological conditions with which we have become familiar on the eastern shore. These variations are, however, of some moment, since they supply missing links in the chain of evidence essential to the correlation of the Nantasket strata. But although Rocky Neck is simply a detached part of Nantasket, we can go no farther west in the study of Nantasket geology; for not only is a natural boundary provided in the drumlins of World's End, Planter's Hill, and Pine

Hill, but beyond these we encounter, in Hingham Harbor and northern Hingham, structural features of a radically distinct type.

The eastern base of Planter's Hill is the typical, coarse, and somewhat reddish granite, which extends eastward in numerous ledges to Weir River Bay. Advancing north along the west shore of Rocky Neck, we find the granite, near dikes 22 and 23, overlain by the basal conglomerate. It is largely composed, as on the Nantasket side, of the more or less angular debris of granite and felsite, including, however, few large fragments, and it has, in consequence, a prevailing reddish tint. Erosion has evidently again cut just to the base of the conglomerate over a considerable area; and, as on Granite Plateau, several thin patches have been isolated by unequal erosion. These outliers show that the conglomerate conforms in the usual manner to the fissures and other inequalities of the original granite floor. The dip is S. E. 0°–10°. The granite rises from beneath the conglomerate on the northwest, forming Granite Head; while on the south the conglomerate is certainly cut off by an oblique fault with a decided upthrow on the south. Hence the conglomerate is naturally thickest toward the east, where the ledges overlook the little valley running northwest to the bay north of Granite Head. In this natural section the conglomerate encloses considerable layers of sandstone and even slate, and the bedding is very distinct. The fault just referred to divides the basal conglomerate into two principal areas; and in going eastward the conglomerate again appears, first in small outliers capping the granite ledges, and then, apparently, in a continuous bed reaching to the shore. This is a drift slope, however; and the outcrops are, perhaps, insufficient to make this inference entirely safe.

These masses of granite and overlying conglomerate must be bounded on the north by a fault transverse to the strike of the conglomerate and reaching from Granite Head to the

eastern shore, the continuation of the boundary fault on the Nantasket side. The downthrow is, of course, to the north, and evidently greatest toward the eastern shore; for north of this fault, on the western shore, we again find the granite and basal conglomerate. The granite rises somewhat abruptly to a height of from twenty to thirty feet on the west end of the hill, and is immediately overlain by the conglomerate, matching Granite Point on the Nantasket side. The hill is precipitous at this end on both the north and south sides, being bounded by fault-scarps; and these natural sections show that the granite is cut off in its eastward extension beneath the conglomerate by a north-south fault having an easterly throw of perhaps 10 or 20 feet (Fig. 12). This fault appears to end in the east-west faults, and accounts for the form of the conglomerate outcrop, as shown on the map. The basal conglomerate on this hill is similar to that south of the boundary fault, except that the pebbles include a large proportion of compact forms of melaphyr, and the red jaspèr is more conspicuous. The dip is S. E. 5°–10°, equivalent to a thickness of thirty or forty feet.

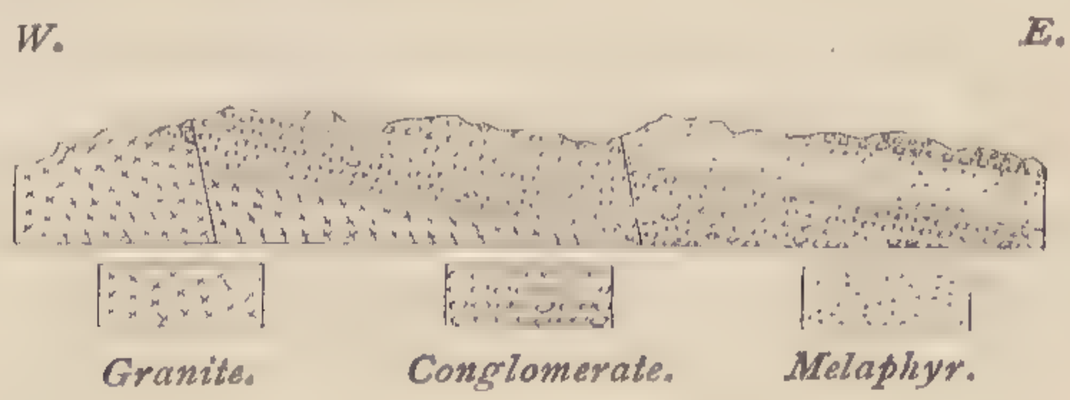


FIG. 12.—AN EAST-WEST SECTION ACROSS ROCKY NECK, NORTH OF THE BOUNDARY FAULT.
SCALE, 1 INCH = 400 FEET.

The conglomerate is certainly separated from the melaphyr on the southeast by a fault, which is probably an extension of the southwest-northeast fault in the granite, already referred to, but with the throw reversed (Fig. 12). This melaphyr is the compact, green and purplish, jaspery variety—the first melaphyr—which normally overlies the basal conglomerate; and it is

indistinguishable from that flow on the east side of the bay. It is never amygdaloidal, but often somewhat brecciated. The fault just referred to must, therefore, downthrow to the southeast, but probably not more than 20 or 30 feet, possibly less. Both this displacement and the preceding one, parallel with it, are evidently added to the boundary fault, so that this now becomes sufficient to conceal entirely the basal conglomerate on the downthrow side. The first melaphyr is overlain in regular order by the second conglomerate (Fig. 12), which is thus, in consequence of the increased displacement, brought *vis à vis* with the strongly contrasting basal conglomerate (Fig. 13). The second conglomerate contains so much melaphyr debris derived from the underlying flow that it is not always easily distinguished from the brecciated portions of the melaphyr. It is also the richest in red jasper of all the Rocky Neck strata, agreeing perfectly in this respect with the same bed in the porphyrite hills of Nantasket. This highly jaspery conglomerate is well exposed on the shore for nearly two hundred feet, before it gives way to the underlying melaphyr, which extends 150 feet farther, but bears several distinct outliers of the conglomerate, as mapped. These outliers are seen to rest upon a very uneven surface of the melaphyr; but the normal dip is plainly S. E. 10° or more. At the northern edge of the melaphyr it seems to end quite abruptly; but the narrow beach between it and the puddingstone on the north is partly occupied by the firm, jaspery, second conglomerate,— another outlier let down by faulting.

We have now reached the north end of the northeast-southwest fault which has already been seen to bound the first melaphyr on the northwest. It appears to be a double fault at this end (Fig. 13); and following it southwest, we find that it encloses not only the depressed outlier of the conglomerate, but also an isolated ledge of the melaphyr with traces of the conglomerate upon it.

The hill or ridge just described, composed of the first and

second conglomerates and the first melaphyr, and terminated by the granite on the west shore, is bounded on the precipitous northern side, as previously stated, by a fault, which, as the map shows, coincides with a dike (30). The dike can only be traced about half-way to the N. E. – S. W. fault, passing under the grass; but both the dike and its displacement undoubtedly continue until the faults meet, as mapped. This dike-fault and the part of the N. E. – S. W. fault northeast of the junction may be regarded as one continuous fault, with the downthrow on the north. That it is an important displacement is evident from the fact that the rocks north of this line are *wholly different* from those south of it. There is first a broad area of non-jaspery conglomerate — a normal puddingstone — sloping gently to the southeast and dipping in the same direction 5°–15°. It forms the eastern shore for about 100 feet; but the true thickness of the bed probably does not exceed 25 feet. This conglomerate is underlain conformably and very clearly by typical, basic, green, amygdaloidal melaphyr, which is identical with that on Melaphyr Peninsula and Melaphyr Plateau (Fig. 13). The melaphyr outcrops broadly around the conglomerate and the exposures of the contact are all that could be desired. The contemporaneous origin of the melaphyr is sufficiently demonstrated by the fact that near the base of the conglomerate, especially, it encloses many water-worn fragments, from three to eighteen inches in diameter, of exactly the same kind of melaphyr. The melaphyr plainly consists of two flows, each of which is amygdaloidal above and compact below, with an aggregate thickness of forty or possibly fifty feet; and this fact seems to identify it with Melaphyr Peninsula, and with the upper flow in the Crescent Hill section — the third melaphyr. If this correlation be made, the displacement along the dike-fault can scarcely fall below 200 or 250 feet.

The east-west fault crossing the summit of the hill, with a southerly throw of ten feet, is very clearly exposed on the west

FIG. 13.—A NORTH-SOUTH SECTION ACROSS ROCKY NECK.
SCALE, 1 INCH = 400 FEET.

side, where it breaks the contact of the conglomerate and melaphyr (Fig. 13). It is nearly parallel in direction, but opposed in throw, to the fault bounding this hill on the north. The melaphyr and conglomerate rise here in a sloping cliff of 20 to 40 feet, extending the entire length of the hill and overlooking the small plain which forms the extremity of the Neck.

The melaphyr north of this fault-scarp is similar to that south of it; but it is underlain on the west by a limited bed of conglomerate, which, dipping S.E. 2°–5°, must abut against the cliff of melaphyr, although the contact is not exposed. This proves the fault, for the northern conglomerate, rising toward the west, could not otherwise fail to appear in the western half of the cliff. This conglomerate is of normal character, with an average thickness not exceeding ten feet. It is plainly cut on the north shore by a north-south fault, sinking the conformable contact with the overlying melaphyr about eight feet on the east. The conglomerate is, in its turn, clearly underlain on the west by a non-amygdaloidal melaphyr, of which about twenty feet are exposed at low tide. Superficially, at least, this melaphyr is highly brecciated, so that it is not quickly distinguished from the conglomerate. It encloses numerous masses of compact melaphyr similar to the matrix, more or less rounded, and of all sizes up to eighteen inches in diameter. It is probably not a conglomerate or tuff, but a very coarse original brecciation, something similar to the melaphyr holding the pseudo-bombs on the north side of Atlantic and Centre Hills. The entire rock is similar in color and texture to the melaphyr of Long Beach Rock and

the coastal area generally ; and it seems impossible to correlate it with anything else in the Nantasket region. But in that case the conglomerate and the highly amygdaloidal melaphyr overlying it must be referred to the very summit of the Nantasket section ; and this amygdaloidal melaphyr north of the fault-scarp is thus widely separated in time from the very similar melaphyr south of the fault. This view also implies the recurrence at the top of the Nantasket section of the basic flows characterizing the middle portion of it.

According to the foregoing interpretations, the Rocky Neck section, as exposed to observation, is evidently far from complete or continuous ; but the following list of the Nantasket strata will show more clearly than either the map or sections just what the deficiencies are :—

Granite.
First conglomerate, basal.
First melaphyr, compact and jaspery.
Second conglomerate, highly jaspery.
Porphyrite, wanting.
Third conglomerate, wanting.
Second melaphyr, wanting.
Fourth conglomerate, wanting.
Third melaphyr, amygdaloidal.
Fifth conglomerate, normal puddingstone.
Fourth melaphyr, compact and brecciated.
Sixth conglomerate, ten feet.
Fifth melaphyr, amygdaloidal.

On referring to the map and sections (Figs. 12 and 13), it becomes obvious that this great break in the middle of the series is due wholly to the east-west dike-fault, which, as previously explained, divides Rocky Neck into two areas having nothing in common so far as the stratigraphy is concerned. This important displacement is quite clearly a continuation of that separating Melaphyr Peninsula from West Porphyrite Hill and dividing the central and coastal areas.

The porphyrite is, possibly, not wholly wanting on Rocky Neck; for the small point jutting into Weir River Bay south of the basal conglomerate and mapped as granite, consists of angular masses, probably overlying a ledge, of a semi-crystalline, red rock, apparently quartzless, and resembling the Nantasket porphyrite. Its rather crystalline texture would indicate a dike of porphyrite breaking through the granite; but if it is effusive, a surface flow, important bounding faults must be assumed to account for its topographic position with reference to the granite.

The Nantasket Peninsula North of Atlantic Hill.

As previously stated, the only exposure of the underlying rocks north of Atlantic Hill is the ledge of slate on the shore south of Thornbush Hill; and with the exception of the ledge of green and gray contorted slate on the railroad northwest of Rockland Hill, which has been doubtfully referred to the principal bed of tuff in the Atlantic Hill section, this is the only considerable outcrop of slate on the Nantasket Peninsula. It is exposed along the shore for about 900 feet and with an extreme breadth across the strike of perhaps 400 feet. It is a rather coarse or arenaceous, purplish slate, distinctly and finely banded with gray, and occasionally with greenish, layers. The strike is N. 65°–70° E.; and the dip is variable, but always low. In the western ledges it is S. 10°–15° or 20° at the most; but in the middle ledges the beds are approximately horizontal, broad contortions or undulations showing gentle dips in various directions; while the eastern ledges show a northerly dip of 10°–20°. This is evidently an oblique section of a flat anticline. It includes no pebbly or distinctly arenaceous beds; and the exposed thickness of the slate, although difficult to estimate, probably does not exceed 40 or 50 feet. The slate is characterized throughout by a distinct cleavage-structure, which strikes N. 80° E., and hades, usually to the north, occasionally to the south, 0°-5°, being always transverse to the bedding

planes. Somewhat prominent joint-planes hade S. about 45°. By taking advantage of the lowest stage of the tide, it is possible to add a little to the meagre knowledge of the geology of northern Hull afforded by the ledges just described. The Toddy Rocks, one fourth mile north of Telegraph Hill, were visited with a boat at low tide and found to be ledges of a bright green slate, with very perfect cleavage, which strikes N. 75° E. and hades to the north 0°–5°. The true bedding lines dip north at low angles, 10°–20°. Some thin and very hard compact layers of a gray color are probably intrusive (trap). This outcrop is evidently essentially similar to that south of Thornbush Hill; and slate of the same general character is the most abundant rock in the drumlins and on the stony beaches of northern Hull. Bowlders of conglomerate and sandstone are so rare as to indicate that they have probably been transported by ice; and we hazard little in regarding the part of Hull between Point Allerton and Windmill Point as having a continuous foundation or axis of slate. One and one half miles east of Point Allerton, and fully a mile south of the line of strike of the slate at the foot of Thornbush Hill, is Harding's Ledge. This is partly bare at low tide, exposing a hard grayish and greenish sandstone varying to a fine conglomerate. It is an undoubted ledge; and these rocks are probably on the line of the anticline of Hough's Neck, which we may suppose to extend by the north side of Grape Island, Bumpkin Island, Strawberry Hill, and Strawberry Ledge to Harding's Ledge. It is manifestly impossible, without going beyond the limits of Hull, to reach any definite conclusion concerning the relations of the slate beds to the conglomerate and melaphyr series. It is probably safe to assume, however, that here, as elsewhere in the Boston Basin, these soft and arenaceous slates normally overlie the conglomerate, the latter appearing, as a rule, only along denuded anticlines. According to this view, not only northern Hull, but the entire peninsula north of Atlantic Hill, is underlain chiefly by slate; and to account for

the broad exposure of the conglomerate series at the southern end of the peninsula we have only to add one more to the east-west displacements with the downthrow on the north which we have observed in the Nantasket ledges, the fault crossing the beach near the base of Atlantic Hill.

THE DIKES OF NANTASKET.

The dikes of this district, as previously stated, consist almost wholly of diabase and are more recent than the bedded rocks. The existence of dikes of melaphyr and porphyrite, at least in the granite and the older strata, is, however, probable, *a priori*; and two dikes of melaphyr have actually been recognized in the Nantasket ledges; while in the granite ledges along the Cohasset shore there is a fine series of porphyrite dikes. The dikes of melaphyr and porphyrite clearly antedate all the diabase dikes, dating, probably, from the effusive eruptions to which they correspond in composition; and they will, therefore, be described first, in each topographic division. Since the special map shows so clearly the location and approximate trend of each dike, and the descriptive lists give in addition the exact trend and the hade, width, and other features, it is only necessary to cite here such additional facts as may be of particular interest.

The Melaphyr Dikes.

No.	Trend.	Hade.	Width in feet.	Remarks.
1	E.–W.	Vertical	3–7	Irregular in form and hade.
2	S. 0°–30° E.	Vertical	32	Regular in form and uniform in texture.

The two dikes belonging to this class have been referred to in connection with the associated flows of melaphyr. The first one (No. 1) breaks through the brecciated and compact greenish gray melaphyr on the north side of Centre Hill. Except in

being more compact and homogeneous, it is very similar, lithologically, to the enclosing melaphyr; and hence is quite inconspicuous and not easily found. The outcrop begins on the north side of the road immediately east of the Waverly House and can be traced due east several hundred feet to the shore. It is somewhat irregular in form, and varies in width from three feet or less to seven feet, narrowing eastward. The hade is also variable, but averages about vertical.

Its compactness, similarity to the enclosing melaphyr, and irregular outline are the characters that especially mark this as an approximately contemporaneous dike. The melaphyr of the dike is firmly welded to that of the walls, and the contacts are clearly neither joint-planes nor fault-fractures. Although this is the only undoubted dike of melaphyr that I have observed in the Nantasket flows, the eye is frequently attracted by sharply defined, vertical, dike-like contacts between the ordinary brecciated, amygdaloidal or scoriaceous melaphyr and more compact forms; but as a rule these cannot be traced far, or only one wall can be found, and it is quite clear, in most cases at least, that they are not dikes in the ordinary sense.

The second dike (2) of the list is much more impressive and interesting than the first, being decidedly the largest of all the Nantasket dikes. It cuts the granite south of the west marsh with a nearly due north-south trend and a width of 32 feet. Its interesting relations to the effusive melaphyr of the western area, and its marked change in form on passing from the granite to the basal conglomerate on the eastern margin of Granite Plateau, have been fully described (page 77); and in these respects, that is, as a clearly exposed volcanic vent the outflows from which can be fully identified, it is, perhaps, unique among the dikes of the Boston Basin. It is exposed, as the map shows, on two islands in the marsh, forming the western edge of one and the eastern edge of the other. It commences on the north with a due north-south trend, but on passing to the southern ledge it changes to S. 10° E., and then to S. 30° E.

It can be traced almost to the northern shore of the bay; but no trace of it could be found in the almost continuous ledges of granite on the south shore. Its last observed course, however, would carry it directly up the mouth of Weir River; and the absence of additional outcrops is not, therefore, evidence of an important displacement. That this great dike should not, on account of its trend, be referred to the third or newest system of diabase dikes is obvious not only from its lithological character, but also and especially from the fact that it is clearly cut by, and hence is older than, one of the east-west diabase dikes (39), the outcrop of the latter continuing directly through the melaphyr dike.

The Diabase Dikes.

The occurrence of the diabase dikes in three systems — two older systems having approximately east-west trends and a newer north-south system — has been noted; and also the fact that the east-west systems form three belts, corresponding in a general way with the principal dislocations of the district. All of the dikes agree in direction with well-determined faults, although often not actually coinciding with a fault of sensible displacement. The two east-west systems are certainly much more closely related to each other than to the north-south system, and since, in the absence of clearly exposed intersections, they are not always readily distinguished, it appears best not to attempt to describe them separately; but we will, instead, follow the classification by belts, commencing with the northern or coastal belt.

Although Mr. Merrill has not observed any marked or constant difference in microscopic characters between the older or east-west dikes and the newer or north-south dikes, they are usually somewhat contrasted in external aspect. The east-west dikes are commonly of a dark greenish gray color, due to the abundance of secondary chloritic minerals and epidote. They are, relatively, chemically stable, resisting atmospheric influ-

ences and preserving glacial striae almost as well as the melaphyr and granite; and they rarely weather brownish, or show in any marked degree peroxidation of the ferruginous compounds. Finally, they are, as a rule, irregularly jointed, exhibiting only exceptionally a regular transverse or prismatic joint-structure. The north-south dikes, on the other hand, are usually black on a fresh fracture and not conspicuously chloritic or epidotic; they weather readily to brownish masses of rounded outline and later to a brown earth; and a well-developed cross or columnar jointing is often a conspicuous feature and never wholly wanting.

East–West Dikes of the Northern or Coastal Belt.

No.	Trend.	Hade.	Width in feet.	Remarks.
3	N. 75°–80° E.	Vert.-N.10°	2.5–3.5	Finely porphyritic.
4	N. 75° E.	S. 15°–20°	3	Slightly porphyritic.
5	N. 80° E.	S. 5°	3–5	Double dike; cut by 11.
6	S. 80° E.	Vertical	3–4	Jogged or faulted in crossing beach.
7	S. 80° E.	Vertical	15–20	Walls irregular and faulted.
8	S. 82° E.	N. 25°	2.75–3	Cross-jointed.
9	S. 80° E.	Vertical	10	Probably divided or composite toward the east.
10	S. 75°–80° E.	Vert.-N.15°	4–5	Irregular in width and hade.
11	S. 75°–80° E.	N. 10°	2.5	Encloses fragments of granite.
12	S. 75° E.	Vertical	3.5–4.5	Encloses fragments of granite and syenite.
13	S. 75°–80° E.	Vert.-N.10°	.75–1.25	Very irregular at east end.
14	S. 75°–80° E.	N. 10°–20°	4.5–7	Very irregular and broken.
15	S. 77° E.	N. 5°–10°	2–4?	No satisfactory exposures.
16	S. 75°–80° E.	Vertical	4	Quite irregular in trend and hade.
17	S. 80° E.	N. 10°–15°	4–5	Regular; probably a branch of 18.
18	S. 75°–80° E.	N. 45°	8	Regular; unusually strong hade.
19	S. 75°–80° E.	N. 30°	8–9	Very irregular and branching.

The dikes of the coastal belt present many interesting and instructive features. As the map plainly shows, they form a well-defined belt coinciding with the immediate shore-line; and

it is very certain that their non-occurrence over the broad area of melaphyr forming Atlantic and Centre Hills cannot be attributed to the absence of exposures. Only three dikes in this belt (3–5) belong to the first or oldest system; while no fewer than fourteen (6–19) find a place in the second system. The older dikes will be described first and, so far as possible, in the topographic order of the outcrops.

On the northeast corner of Atlantic Hill, the melaphyr south of the great dike (7) is, for a breadth of nearly twenty feet, very shaly, being divided into thin vertical layers running N. 80° E. Careful examination discovers in the middle of this shaly zone a dike (3) having the same trend. It must meet the great dike near the east side of Valley Beach; and is probably cut and slipped by it, although the intersection is not exposed; while to the westward it passes under the shingle beach. It is finely porphyritic, and reappears with the same lithological character, width, and hade on Gun Rock and the half-tide ledge to the eastward.

From 25 to 75 feet south of the melaphyr dike (1) on Centre Hill, and extending from near the end of Centre Hill Avenue across the ledges to the shore, is the narrow chasm holding the very obscure outcrops of the next dike (4), the attitude and dimensions of which are taken from the fissure rather than from the dike itself. It trends toward the middle of Gun Rock, but no traces of it could be found on that promontory. Nearly 150 feet south of this dike is a broader chasm or depression, in which a small dike occurs, or possibly in the lower end of the chasm two small parallel dikes with several feet of melaphyr between them. Looking eastward across the bay we see in line with this depression a more sharply defined chasm in the first ledge south of Gun Rock. Here the double dike is well developed in a fissure five feet wide, the south dike measuring 2.5 feet and the north dike 1 foot. Keeping this course, we find the same double dike cutting the ledge east of Gun Rock. The two members here measure 3 and 1.5 feet respec-

tively, with 3 feet of separating melaphyr. The dike is thus widening eastward, and it undoubtedly begins on Centre Hill near where it is first observed. In the third or eastern outcrop it is very plainly cut by a dike of the second system (11), this intersection (Fig. 14) being the one chiefly relied upon to determine the relative ages of the two systems

We pass now to the dikes of the second system, commencing with the three typical examples crossing Long Beach Rock. The most northerly of these (10) is about 50 feet from the north end of the ledge at low tide. It crosses the strike of the conglomerate, but the intersection is under water. About 60 feet of the melaphyr separate this from the large dike (9), which crosses the eastern end of the conglomerate, and is there seen to be attended by slight faulting, the contact between the conglomerate and melaphyr being displaced in such a way as to show a downthrow to the north of about 5 feet. The third dike (8) is 120 feet south of this and crosses the conglomerate contact without apparent faulting. It is, perhaps, the most distinctly cross-jointed of all the east-west dikes. These three dikes appear to cross the low-tide ledge north of Valley Beach; and 10 appears again on the south side of Gun Rock, but with a northerly hade of 15°. In the place of 9 we find on the shore south of Gun Rock a series of six small parallel dikes, with an aggregate thickness of 9 feet, which appear to be the equivalent and continuation of it. But 8, if it extends this far, must pass under the beach.

The shore along the northern base of Atlantic and Centre Hills appears to be determined immediately by the great dike (7), which must also pass under the beach south of Gun Rock. It shows several small faults or lateral shifts of from 3 to 8 feet at the base of Atlantic Hill, and suffers a displacement of perhaps 10 feet in crossing Valley Beach, passing beneath the foot-bridge in front of the Waverly House. The smaller dike (6) parallel with this is well exposed in front of the Pacific House, but cannot be traced more than half-way to

the Waverly House, although there are plenty of ledges on its course. It is quite possible, however, that it passes under the street, in front of the Waverly House, as far as Valley Beach. It is perhaps possible, also, that this dike cuts 4 and 5, but more probable that they end before reaching it. On crossing the beach east of the Pacific House, this dike is seen cutting through the first ledge, near the road. Its characters are unchanged; but in crossing the beach it is evidently jogged or shifted to the south about 25 feet, as if a transverse fault intervened (see map).

Gun Rock, with its broad surface of bare melaphyr, is an uncommonly favorable point for the study of dikes. As already pointed out, it embraces two dikes (3 and 5) of the first system and five dikes (9–13) of the second system. Beginning on the west shore we have first the double dike (5) in a fissure about five feet wide. About 23 feet north of this begins the series of small dikes supposed to be the extension of the large dike (9) on Long Beach Rock. The following succession is readily made out:—

(1)	Diabase,	0.5 feet.	Separating melaphyr,		2 feet.
(2)	"	2.0 "	"	"	1 "
(3)	"	3.0 "	"	"	2 "
(4)	"	1.0 "	"	"	3 "
(5)	"	1.5 "	"	"	3 "
(6)	"	1.0 "			
		9 feet.			11 feet.

Some 75 feet farther north, at the base of the steep slope, is the extension of 10; and about 100 feet of melaphyr separates this from 11, which hades N. 10° and, passing under the house at the top of the cliff, reappears on the east side of the ledge, and again in the same direct line on the ledge east of Gun Rock, where it cuts the double dike of the first system (Fig. 14). The intersection is clear and well exposed; and, so far as one intersection can, it establishes the relations of these two

systems. It is a curious fact, however, that of the ten possible intersections of the dikes of these two systems on or near Gun Rock, only this one is actually exposed above the water.

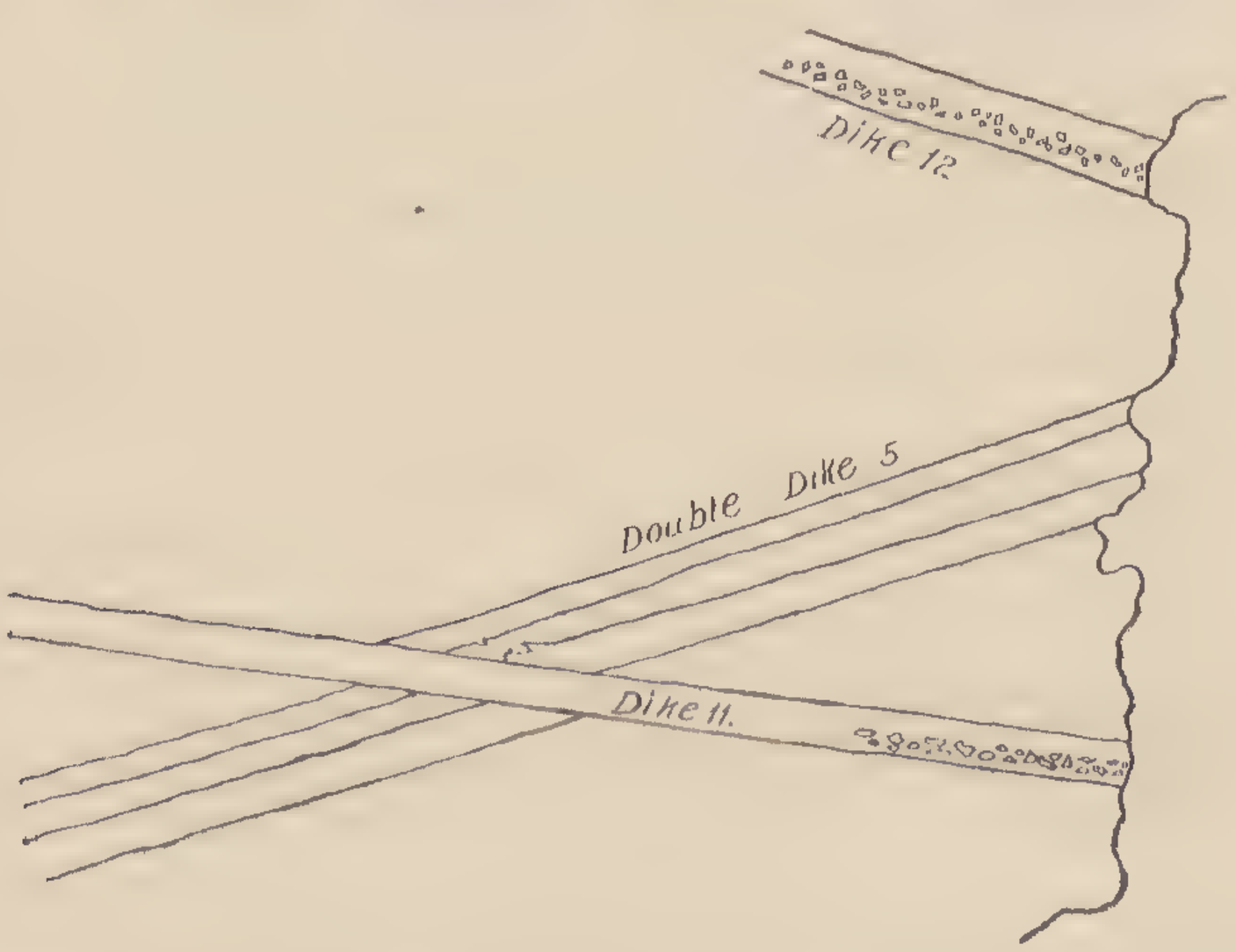


FIG. 14.—PLAN SHOWING THE INTERSECTION OF DIKES ON THE SHORE, EAST OF GUN ROCK, AND THE ENCLOSED FRAGMENTS IN DIKES 11 AND 12. SCALE, 1 INCH =25 FEET.

The next dike in regular order is the continuation of 3 of the first system, and the exposure is perfect from one side of the promontory to the other. About 40 feet north of this dike, and parallel with it in strike and hade, is an interesting quartz vein one inch or a little more in width. It is perfectly straight and continuous, its outcrop dividing the entire mass of Gun Rock by one sharply-defined white line. Dike 12 of the second system is about 120 feet north of 11; and nearly 20 feet farther north is 13, a parallel and much smaller dike. Dike 13 is closely parallel to 11, appearing just to clear the extremity of the ledge east of Gun Rock and to be continued in a similar dike (13) on Green Hill Ledge. But dike 12 takes a more diagonal course, being, on the eastern ledge, 100 feet from 13 and only 42 feet from 11. The large dike (12) is, perhaps, the most

interesting of the series. It crosses Gun Rock and all the ledges to the east, increasing in width from 3 to 4.5 feet. On the summit of Gun Rock it makes a clear intersection of the quartz vein just described, without faulting it. Throughout its entire extent this dike has the appearance of being very coarsely porphyritic along a zone from six inches to a foot wide, between the middle of the dike and the south wall. Careful examination shows, however, that it is not truly porphyritic, but what appear to be indigenous feldspars are really angular fragments of a coarsely crystalline feldspathic rock which is, apparently, partly granite but mainly syenite. The fragments range from the smallest size up to six inches or more in length; and their true character is most obvious on the eastern ledge (Fig. 14). Dike 11 presents the same feature for a part of its course. The enclosed fragments in this dike are chiefly coarse granite; and they begin very abruptly at a point about 20 feet from the intersection of the double dike and the same distance from the shore. They are of all sizes up to six inches and, as in 12, are crowded in a layer from 6 to 12 inches wide between the middle and south wall of the dike. Although no granitic rocks are developed on the surface nearer to Gun Rock than Jerusalem Road, the inference is irresistible that they actually underlie Gun Rock; and the restricted distribution of the fragments in the dikes is a very plain indication that the upward movement of the melted rock in these fissures had nearly ceased before the underlying granitic rocks were sufficiently disintegrated to yield this debris.

The intersection of the quartz vein on Gun Rock by a dike of the second system, and its perfect parallelism with the dikes of the first system, show that it probably dates from the formation of the first system, or else from some period between the two systems. South of this vein is another, smaller and parallel with it, but not observed to meet any of the dikes. Under the Park House on the summit of Centre Hill are two

conspicuous quartz veins from 2 to 3 inches wide, parallel, and 75 feet apart. Curiously enough, however, they conform in direction with the second system of dikes. This is only one of several indications that the dikes of the two systems are not widely separated in time.

The outermost dike on Gun Rock (13) is undoubtedly continued in the Green Hill conglomerate, as mapped. In the eastern half of the ledge, both this dike and 14 are especially characterized by extreme irregularity and lack of continuity, the conglomerate, apparently, having been repeatedly faulted after they were formed. One result of this disturbance is that they converge eastward, so that, although 50 feet apart along the north-south dike (62) they are almost in contact at the east end of the ledge. About 50 feet from the extreme northern edge of the conglomerate and 22 feet north of 14 on 62, but diverging from it eastward, is dike 15. It is not well exposed, but it is clearly a dike of the second system. The chief interest at this point centers in the clear intersections of all these dikes (13–15) by the single small representative (62), in all the coastal area, of the third system of dikes.

Dike 16, on the north side of Green Hill Rock, is quite irregular in trend, but doubtless belongs to the second system. If so, it is probably parallel with, and passes to the south of, all the dikes (17–19) on Black Rock. Dikes 17 and 18 converge eastward, their outcrops being 50 feet apart at the west end of the island and almost in contact at the east end. Dike 19 on the northeast corner of the island ends abruptly on the west and is much given to irregular branching, one of the easterly branches splitting a prominent vein of quartz.

By far the most prominent set of joints in the rocks of the coastal area trends due north and south. They form or bound the valley between Atlantic and Centre Hills and are very marked along the shore of Centre Hill and Gun Rock, and, in fact, along the entire Nantasket coast, producing the many fissures and chasms that indent the shore. It is certainly,

therefore, a very interesting fact that the only dike of the coastal area conforming in direction with these joints is the one small example of the third system. East-west joints are also well developed in the coastal melaphyr; but they have, with few exceptions, a decided southerly hade of 20° to 30°; while the east-west dikes, almost without exception, are vertical or have a northerly hade, showing a tendency to be, as a rule, approximately normal to the bedding planes of the melaphyr, tuff, and conglomerate.

East-West Dikes of the Central Belt.

No.	Trend.	Hade.	Width in feet.	Remarks.
20	N. 78° E.	Vert.-N.15°	1 6	North end of Rocky Neck.
21	N. 77° E.	N. 15°–20	3 3.5	Probably a branch of 20.
22	N. 78° E.	Vert.–N. 3	8 12	Probably faulted six times.
23	N. 75°–80° E.	Vertical	10 15	Parallel with 22 on Rocky Neck.
24	N. 75° E.	S. 10	5 6	Porphyritic. Parallel with 22.
25	N. 80° E.	N. 20°–25	1 5	Porphyritic; a fault-dike.
26	S. 75° E.	N. 5	2.5 3	Cuts 25 on Melaphyr Plateau.
27	S. 75° E.	N. 15	3	Porphyritic; a fault-dike.
28	S. 80° E.	Vertical	6	Regular; and no apparent faults.
29	S. 80° E.	Vert.-N.10°	6–8 5	Possibly not one continuous dike.
30	S. 75° E.	N. 10	6	An important fault-dike.
31	S. 80° E.	N. 20°–30°	8 9	Possibly a continuation of 34.
32	S. 80° E.	N. 15°–20	3 4	Branch of 31.
33	S. 75° E.	N. 15°–20	2	Probably a branch of 31.
34	S. 75°–80° E.	N. 40°–50	8 10	Double dike.
35	S. 75°–77° E.	N. 10°–15°	5.5 7	Unrecognized west of the railroad.
36	E.–W.	N. 5°–10	1 1.5	Branch of 35.

The central belt extends from the shore of Strait's Pond, near Folsom's Island, across Conglomerate and Melaphyr Plateaus, and thence along the south shore of Nantasket Harbor to Rocky Neck. Both of the east-west systems are represented in this belt; but, as before, the second system largely predominates. Although the exposures are, as a rule, less satisfactory than in the coastal belt, individual dikes can, in several instances, be

traced much farther, the extreme distance being one and a half miles. It is a singular fact that the number of observed dikes is exactly the same as in the coastal belt.

The most northerly dikes of the first system (20 and 21) on the northern extremity of Rocky Neck are of similar character, and, converging eastward, may be regarded as, possibly, branches of the same dike. The next dike of this system (22) first appears on the western shore of Rocky Neck with a width of from 8 to 10 feet; and only 20 feet south of, and parallel with, it is the very similar companion dike (23), enclosing a large wedge of granite. These two dikes can be traced in the same direct line only 400 or 500 feet at the farthest; but it is quite certain that they are shifted to the eastward by the fault between the granite and conglomerate and continue to the east shore. This is clearly the case with the northern one, which may be safely correlated with the dike of the same number in the western area, although it is 100 feet too far north to be just in line with it. Crossing the bay, we find this dike, with a width of 12 feet, dividing the half-tide ledge of melaphyr off Granite Point; and striking the shore on the north side of the point, with a trend N. 80° E., it takes a perfectly straight course to the southwest corner of East Porphyrite Hill, where it is jogged to the south its own width and, skirting the edge of the conglomerate, is lost beneath the grass. It is probably either broken here by a fault not marked on the map, or dies out and is resumed along a parallel line; for what appears to be essentially the same dike begins a little to the northward and, though cut and shifted by three dikes of the younger system (27, 29, 31), can be traced across the hill to the shore, where it is well exposed with a breadth of 9 feet. Closely parallel with this dike, on East Porphyrite Hill, and sharing the same accidents, but with the intersections less clearly exposed, is 24; and this dike, which is distinctly porphyritic, might safely be correlated with the dike of the same general character (25) east of the bay and the railroad, but for the fact that it lies so far to the

north as to involve a displacement of improbable magnitude. The latter (25) is a good example of a fault-dike (Fig. 5) and its northerly hade agrees well with the throw. It is cut on the northern edge of Melaphyr Plateau by the most northerly dike of the second system (26); and near the railroad both of these dikes are dislocated by the same transverse fracture, the horizontal displacement being 7 feet for dike 26 and, on account of its greater hade, 15 feet for dike 25.

The fault-dike (27) on East Porphyrite Hill is one of the most important in the district, marking a vertical slip of about 50 feet. It is porphyritic and strikingly similar to 25, east of the bay; but since they belong, one to the first and the other to the second system, it seems best not to connect them. This is, however, one of many indications that the two systems are not very distinct, chronologically. The next dike (28), though presenting precisely the same characters on Rocky Neck and Melaphyr Peninsula, cannot be identified on East Porphyrite Hill; for it seems best to connect the next dike to the south on the hill (29) with the dike south of 28 on Rocky Neck. The last-mentioned dike (29), like 27, breaks the dikes of the first system on East Porphyrite Hill; and it is certainly continued on the east side of the bay. In fact it can be identified with reasonable certainty, as shown on the map, from east of Hull Street to the western shore of Rocky Neck. The outcrop on the north side of West Porphyrite Hill, however, is quite uncertain; and it may be that what is regarded here as one continuous dike may include two or three independent dikes. In contrast with this dike of exceptional length, the next dike (30) has been recognized only on the west side of Rocky Neck. It is interesting chiefly on account of the important displacement which accompanies it, being the only clear fault-dike on Rocky Neck.

The next dike (31) is especially characterized by its strong northerly hade. It probably ends westward against the fault between Cliff Plateau and West Porphyrite Hill. At any rate,

it begins abruptly and with its full width on the northern escarpment of the plateau, not a trace of it or of 33, which is probably a branch of 31, appearing on the bare ledges of the hill. It crosses the composite N.–S. dike (66) without perceptible displacement, slips the dikes of the first system on East Porphyrite Hill and is itself thrown abruptly to the south about 25 feet at the eastern base of the hill. It crosses the bay without further important displacement and is readily recognized on both sides of the railroad by its width and hade. It can be followed by frequent outcrops across Melaphyr Plateau, gradually approaching and appearing to unite with 29. But they are widely separated in the conglomerate ledges beyond, 31, on account of its greater hade, suffering a greater lateral displacement in crossing the fault between Melaphyr and Conglomerate Plateaus. In the ledges west of Hull Street some interesting inclusions of conglomerate are clearly exposed. The last ap-

FIG. 15.—NATURAL SECTION OF THE INCLINED DOUBLE DIKE (34) ON THE WESTERN SHORE OF ROCKY NECK. SCALE, 1 INCH = 6 FEET.

pearance of this dike to the eastward is on the shore of Strait's Pond, more than a mile from its starting point. On Melaphyr Plateau it appears to give off a branch (32), which can be traced for a considerable distance parallel with the main dike.

Granite Head on Rocky Neck is crossed near the northern edge by a double dike (34) having a northerly hade of 50° and the following section from south to north: main dike, 7 to 8 feet; granite parting, 6 to 18 inches; small dike, 15 inches (Fig. 15). It can be traced entirely across the head, and presents the same section and hade in each escarpment. This dike crosses the valley occupied by the boundary fault without sensible displacement and reappears on the opposite slope at the point where it crosses the great N. E.–S. W. fault, which here downthrows to the southeast. There are indications, however, that the dike is subsequent to the fault and has simply been jogged in crossing it; for it is shifted or jogged to the north some 50 feet in crossing the fault. If the fault were subsequent to the dike, the displacement should be in just the opposite direction. The character of the dike is unchanged, except that it is simple instead of composite, no trace of the smaller member being observed. On account of the hade, the outcrop curves in passing down the hill to the shore; but it is not clear enough to determine with certainty its relations to 22. Crossing Weir River Bay in the same direct line, and apparently without displacement, it reappears as a double dike with a strong northerly hade (40°–50°) on the southwest corner of West Porphyrite Hill. The section here from south to north is: diabase, 3 feet; conglomerate, 8 feet; and diabase, 7 feet. The hade is most marked in the southern member, which is possibly a branch of the other, but more probably an independent dike; for on Cliff Plateau they are reversed in position, the small dike, which is now on the north, retaining its stronger hade. Near the eastern edge of the plateau it suddenly disappears, apparently joining 22; possibly, however, it is continued along a more northerly line by the other inclined dike (31). The

last of the large dikes of this belt (35) first appears immediately east of the railroad, at the junction of the conglomerate and underlying melaphyr, and can be traced thence directly across Melaphyr Plateau, where, passing beneath the private road, it reappears in the eastern part of Conglomerate Plateau. The small dike (36) south of 35 near the railroad is, doubtless, a branch of the latter.

East–West Dikes of the Southern Belt.

No.	Trend.	Hade.	Width in feet.	Remarks.
37	N. 75° E.	N. 10°?	5?	Cuts 44 and 45?
38	N. 70° E.	Vert.–N. 5°	6–7	Porphyritic and branched.
39	N. 80° E.	N. ?	6–10?	Cuts the great melaphyr dike.
40	N. 88° E.	Vert.-N.10°	3.5–4.5	Irregular.
41	N. 85° E.	S. 10°	4.5	Possibly unites with 40.
42	N. 75°–80° E.	N. 10°	6–7	In granite; regular.
43	S. 80° E.	N. 10°	.25–.5	Very regular and continuous.
44	S. 73° E.	N. 10°	2.5–4	Ends abruptly toward the east.
45	S. 75°–80° E.	N. ?	2?	Imperfectly exposed.
46	S. 80° E.	N. 5°–10°	10–12	Regular and continuous.
47	S. 80° E.	N. 10°	6	Branch of 44.
48	S. 85° E.	N. 10°	7	" " "
49	S. 75° E.	N. 10°	.5–1	" " ..
50	S. 72° E.	N. 15°–20°	.5–.75	" " "
51	S. 80° E.	N. ?	7	Porphyritic.
52	S. 75°–80° E.	N. 5°–10°	6–8	"

On account of the marshes, the dikes of the southern belt appear much less continuous than those of the central belt; and they present, on the whole, fewer points of interest. Although six dikes in this belt are referred in the table to the first system, it is doubtful in several cases whether this reference should stand. Thus 37, on Great Hill, has the normal trend of the first system, but it appears to cut two small dikes (44 and 45) of the second system. The two systems are thus no longer distinct in both age and trend, as in the coastal area. Dike 38 has the extreme trend of the first system (N. 70° E.). It appears first on the west shore of Weir River Bay and can be traced about half-way across Granite Plateau, or until it

meets the great dike of the second system (46). It is somewhat branching as well as porphyritic, and crosses the channel without sensible displacement, although it is somewhat jogged in the plateau. The E.–W. dike (39) in the granite south of the west marsh is imperfectly exposed; and its chief point of interest is that it cuts the great melaphyr dike (2).

The dikes beyond the east marsh (40 and 41) have rather noncommittal trends, not belonging distinctly to either system. These are, possibly, extensions of the Great Hill dikes; but it is impossible to prove it. They converge eastward and upward. The dike in the granite southeast of Round Hill (42), on the other hand, is, so far as can be seen, a very typical example of the first system.

The most northerly dike of the second system in this belt is the smallest one, the solitary dike on Crescent Hill (43). It can be traced continuously across the conglomerate and melaphyr from the western to the eastern face of the hill. If it were continued across the railroad in the same direct line it would strike Great Hill about 40 feet from the northern end; but no trace of it could be found in the bare ledges of conglomerate and sandstone. Advancing south across Great Hill, we come first to dikes 44 and 45, which, as already stated, appear to be cut by 37 of the first system.. These two dikes are somewhat converging eastward, and 44 ends very abruptly in the conglomerate before reaching the face of the hill. The principal dike of this entire belt is 46, which begins on the western shore of Granite Plateau with a breadth of about 12 feet. It is jogged to the north 8 or 10 feet in ascending the slope, and cannot be clearly traced more than half-way across the plateau, passing under the grass; but there is a natural path for it under the narrow meadow along the north side of the high, precipitous ledge of granite and conglomerate to the western marsh. Here it is directly in line with what is clearly the same dike in Great Hill. On the precipitous western face of Great Hill, just north of the junction of the conglomerate and granite, it

measures 11.5 feet ; and about half-way across the hill it appears to divide into two nearly equal dikes, which are separately numbered (47 and 48). Near the point of bifurcation, which is, unfortunately, concealed, a much smaller branch (49) starts from the north side and can be traced across to the western cliff. The similar small dike (50) just south of 46, on the western shore of Granite Plateau is probably also a branch of this main, parent dike. Parallel with 46 on the south is 51, which can be traced for about the same distance across Great Hill, crossing the boundary fault between the conglomerate and the granite without sensible displacement. The most southerly dike on Granite Plateau (52) is, perhaps, a continuation of 51. It is first seen about half-way across the plateau and can be followed to the western shore of Weir River Bay, crossing and probably cutting 38 under the water.

East–West Dikes South of Weir River.

No.	Trend.	Hade.	Width in feet.	Remarks.
53	N. 80° E.	N. 5°–10°	1	In granite west of railroad.
54	N. 80° E.	N. 5°–10°	3	" " " " "
55	N. 80° E.	N. 10°–15°	3.5	" " " " "
56	N. 80° E.	N. 10°	4 ?	" " " " "
57	N. 80° E.			" " east " "
58	N 80° E.	N. 30°–40°	10–15?	" " " " "
59	S. 80° E.	N. 35°	4	" " west " "
60	S. 85° E.	N. 10°	7	" " " " "
61	E.–W.	S. 15°	2.5	" " east " "

No special or systematic search has been made for dikes among the granite ledges south of Weir River Bay ; and the few that were casually observed have been noted chiefly to render the special map more uniform and complete, and not on account of their intrinsic interest. It should be understood, however, that these outlying non-sedimentary areas of the map have not been uniformly treated in this respect, and undoubtedly many dikes have been overlooked, especially west of

the bay and along Rockland Street and Jerusalem Road. The dikes of this section may be regarded as forming a fourth east-west belt, and it is noteworthy that, for the first time, the older system predominates. The outcrops are so imperfect that no attempt will be made to describe these dikes in detail.

North–South Dikes.

No.	Trend.	Hade.	Width in feet.	Remarks.
62	N.–S.	W. 3°–5°	.75-1.75	Cuts 13, 14, and 15.
63	N.–S.			Imperfect exposure.
64	N.–S.	W. 10°	1.5	Irregular and interrupted.
65	N.–S.			Imperfect exposure.
66	N.–S.	Vertical	40	Composite, six parallel dikes.
67	N.–S.	Vertical	3	Probably ends against fault on the south.
68	N.–S.	E. 3°	2.–2.25	
69	N.–S.	Vertical	1–1.5	
70	N. 15° E.	W. 5°–10°	2.5	In granite south of Weir River Bay.

The dikes of the third or newest system, with the normal trend N.–S., have their best development in the central and western areas, only one having been observed in the coastal area and none on Rocky Neck. Unfortunately, the only clear and satisfactory intersections with the east-west dikes are those afforded by the small dike in the Green Hill ledge; but that the dikes of this system are all of about the same age, and newer than the east-west dikes, there can, I think, be no reasonable doubt. They are, as previously explained, darker colored (less chloritic and epidotic) than the older dikes, more prone to weather brownish and to disintegrate on exposure, and more generally characterized by transverse or columnar jointing.

The single small example of this system in the coastal area (62) breaks through the Green Hill conglomerate and cuts all the east-west dikes (13, 14, 15) in this ledge, without sensibly displacing them. But it is itself slipped or jogged to the west 4 feet near its intersection with 14; and north of 15 it is

double, giving off a branch parallel with itself. It runs directly toward the middle of Green Hill Rock, but no trace of it can be found in this bare mass of porphyrite.

The fault bounding Melaphyr Plateau on the west is accompanied by several small dikes, one of which (64) can be traced, with some interruptions and dislocations, the entire breadth of the plateau, crossing and probably cutting all the east-west dikes. The most important and decidedly the most interesting of all the dikes of this system is the parallel series (66) separating East Porphyrite Hill and Cliff Plateau. Near the shore these afford the following section from east to west :—

(1)	Diabase,	9.75	feet.	Separating melaphyr,		3.	feet.
(2)	"	4.25	"	"	conglomerate,	5.75.	"
(3)	"	7.5	"	"	"	8.	"
(4)	"	6.5	"	"	"	50.	"
(5)	"	11.25	"	"	"	8.	"
(6)	"	.5	foot.				
		39.75	feet.			74.75	feet.

This composite dike or series of dikes is thus equivalent to about 40 feet of diabase and 75 feet of separating conglomerate and melaphyr, or 115 feet for the entire fractured zone. The series is actually exposed for only a few rods; but there is a clear path for it between Conglomerate Hill and Cliff Plateau to the northern end of the western marsh. Almost in the same direct line at the southern end of the marsh is the largest of all the Nantasket dikes (2), which might be regarded as due to the union and continuation of the composite dike. This view is precluded, however, by the lithological contrast, the southern dike being a true melaphyr and undoubtedly contemporaneous with the first flow of that rock, while the northern or composite dike, representing the latest period of igneous activity at Nantasket, is very much newer. Probably both the melaphyr dike and the composite dike are intercepted by the boundary fault under the western marsh.

The three-foot dike (67) so clearly exposed on the north shore of Melaphyr Peninsula and traceable across West Porphyrite Hill certainly does not extend so far in this line as Granite Plateau, probably ending under the water against the N. E.–S. W. fault. Nearly 200 feet west of this line, on the north shore of the plateau, is 68, which can be traced about 150 feet back from the water; and about 500 feet farther west, following the shore, is 69, of which only about 50 feet in length are exposed.

DIKES ON THE COHASSET AND SCITUATE SHORE.

Dikes are abundant in the granitic rocks south of Nantasket and the boundary faults; in fact, almost every large ledge or considerable exposure of the granite and diorite shows upon careful examination one or more dikes of diabase. As a rule, however, except along the shore, where the almost continuous ledges are clean and bare, the outcrops of the dikes are obscure and can be correlated only to a limited extent; *i. e.*, the same dike can rarely be traced with certainty from one outcrop to another. And when we further consider that the dikes naturally tend, through their more rapid erosion, to follow the depressions and the drift-covered portions of the surface; and also that the drift-deposits and marshes are continuous over large areas, especially toward the south and south-east, the futility of attempting to trace out or map the dikes of Cohasset and Scituate becomes apparent. In the more limited Nantasket area the conditions are comparatively favorable for such thorough work; but it is probable that even here many dikes are wholly concealed, and the map claims to represent with only approximate accuracy and completeness the dikes which are actually exposed. Particular attention was given to the Nantasket dikes, because it was seen that the outcrops are sufficient to permit of their correlation with the faults of the district and in systems of different ages; and about all that it has seemed wise to attempt in the study of the dikes of Cohasset and

Scituate is to determine to what extent they can be referred to the same systems as the Nantasket dikes. Systematic observations for this purpose were confined to the immediate vicinity of the shore; and the following paragraphs and accompanying lists give the results of a complete canvass of the littoral dikes from Green Hill to the shore beyond the Glades. No attempt has been made to trace any of the dikes inland or beyond the clean exposures afforded by the waves; but such casual observations as have been made away from the shore indicate that the littoral zone is, in the number and trends of the dikes, representative of the entire area. No dikes have been represented on the general map, partly on account of the inconveniently small scale, but chiefly to avoid giving the impression of great inequality in the distribution of the dikes.

It is readily apparent that the dikes of Cohasset and Scituate exhibit a general agreement in character and trend with those of Nantasket. No dikes of melaphyr have been certainly identified; but in their place, as previously explained (page 105), there is a well-defined series of porphyrite dikes. These are clearly older than all of the diabase dikes and probably date from the Nantasket flows of porphyrite. Each of the three systems of diabase dikes is clearly represented, and the exposed intersections show that their relative ages are essentially unchanged. But the oldest system, having the normal trend N. 75° to 80° E., largely predominates, though, as at Nantasket, it cannot always be clearly distinguished from the second system, with the normal trend S. 75° to 80° E. Only a few dikes can be referred to the second system. The dikes of the newest or N.–S. system also are relatively less numerous than in the Nantasket area; and it is especially noteworthy that they become less numerous eastward, not a single clear example having been observed beyond the Cohasset Rocks or more than three fourths of a mile east of Green Hill Beach. This apparent limitation of the newer dikes to the Nantasket area and its immediate vicinity is an interesting and suggestive fact,

but a more extended study would be required to discover its full significance. An occasional dike only, such as 92, 109, 114, 136, etc., is distinctly aberrant or ambiguous in trend; and some of these afford intersections determining the relative age and hence the system. Although faults are, perhaps, as numerous in Cohasset as in Nantasket, none have been definitely located; and we can only conjecture that their relations to the dikes are unchanged. The dikes are often observed to coincide with prominent joint-planes in the granite; but as at Nantasket, the joint-structure is evidently mainly of more recent origin than the dikes.

The Porphyrite Dikes.

No.	Trend.	Hade.	Width in feet.	Remarks.
71	N. 5° E.	E. 15°–20°	4	In granite on Green Hill Beach.
72	N. 30° E.	E. 10°	3	75′ E. of 71; irregular.
73	N. 15° E.	Vertical	18	15′ E. of 72; imperfectly exposed.
74	N. 5° E.	Vertical	2	250′ E. of 73; near Black Rock House.
75	N. 18° E.	E. 5°	8	Near Black Rock House; cut by 88.
76	N. 5° E.	Vertical	13–14	Behind Black Rock House; cut by 88 and 89.
77	N. 40° E.	N.W. 10°–15°	4–5	Branch of 76; cut by 88 and 89.
78	N.–S.	Vertical	4–6	About 450′ E. of 77; cut by 89.
79	N.–S.	Vertical	10–15	
80	N. 20° E.	Vertical	8–10	About 2550′ E. of Forest Ave.; cut by 150.
81	N.–S.	Vertical	8–10	About 3000′ E. of Forest Ave.; cut by 90 and 91.
82	N. 20° E.	Vertical	1–1.5	About 450′ E. of 81.
83	N. 20° E.	Vertical	2–3	6′ east of 82; probably connected with 81.
84	N. 15° E.	Vertical	6	Near 83; cut by 92 and 93.
85	N. 15° E.	Vertical	25–30	About 100′ E. of 84: cut by 94.
86	N. 15° E.	Vertical	3–4	About 200′ E. of 85; also cut by 94.
87	N. 10° E.	E. 10°	8–8.5	West end of Pleasant Beach; cut by 97 and 98.

The dikes of this series have not been observed along the entire shore, but only for about one mile, between Green Hill Beach and Pleasant Beach or Walnut Angle. This is the comparatively straight and eminently rock-bound part of the

shore known as Cohasset Rocks. Although it is convenient to class all the dikes of the above list, provisionally, as porphyrite, it is well to bear in mind that a few at least are more basic and that the list quite possibly includes some melaphyr dikes. The chief points of interest presented by the porphyrite dikes have been noted in connection with the Black Rock flow; while most of the details of any importance, including especially those required for the identification of the individual dikes, are presented in the table. We learn from the table that nine of the seventeen dikes are visibly cut by the oldest system of diabase dikes. On account of the approximate agreement in trend, intersections by the north-south diabase dikes were scarcely to be expected; but, fortunately, one such is presented; and it is, perhaps, the prettiest and most unique phenomenon to be observed among all the dikes of this district. The relations of the two dikes are shown in Fig. 16. The diabase dike (150) advances obliquely from the south until it strikes the east wall of the porphyrite dike (80), follows this wall for 25 feet, amputating a branch of the porphyrite dike, and then passes in a graceful double curve diagonally through the latter and follows the west wall as far as either can be traced,—24 feet. The intersecting dike is a typical example of the third system of diabase dikes—black, brownish-weathering, and beautifully cross-jointed. This porphyrite dike (80) is the one affording the analysis given on page 59. On the north

FIG. 16.—PLAN SHOWING THE INTERSECTION OF A PORPHYRITE DIKE (80) BY A DIABASE DIKE (150) ON THE COHASSET ROCKS. SCALE, 1 INCH = 25 FEET.

side of Beach Island, near Sandy Beach, is a small exposure of a porphyrite (?) dike—N. 5° E., 4 feet, vertical—which is cut off by a fault.

The Diabase Dikes.

No attempt is made in the list of E.–W. dikes to distinguish or separate the first and second systems; but in both this and the N.–S. list the dikes are described in topographic order, beginning in each case at the western end of the Cohasset Rocks, near Green Hill Beach and Forest Avenue. The data of the lists are sufficient for the identification of the individual dikes, if taken in order; but in the brief notes which follow the lists, some additional landmarks and bearings are given.

East–West Dikes.

No.	Trend.	Hade.	Width in feet.	Remarks.
88	N. 80° E.	S. 5°	3.5	Coarsely porphyritic; cuts 75, 76, and 77.
89	N. 80° E.	Vertical	6.5–7	Exposed about 750′; cuts 76, 77, and 78.
90	N. 72° E.	N. 5°	25–30	Branches toward east end: cuts 81; cut by 152 3–4.
90*a*	N. 85° E.	N. 5°	2–3	A northern branch of 90.
91	N. 85° E.	S. 5°	1.5–2	A south. branch of 90; cuts 81.
92	E.–W.	Vertical	2–3	Exposed over 300′; probably unites with 93.
93	N. 85° E.	S. 5°	2–3	8′ S. of 92; 92 and 93 cut 84.
94	N. 80° E.	Vertical	9	Exposed about 300′; cuts 85 and 86; magnetic.
95	N. 80° E.	S. 5°	3–3.5	60′ S. of 94; cut by 156.
96	N. 80° E.	Vert.–S. 5°	8	75′ S. of 95; parallel with flow-structure of granite.
97	N. 80° E.	N. 15°–20°	4–5	125′ S. of 96; cuts 87.
98	N. 80° E.	Vertical	1–2	50′ S. of 97; irregular; cuts 87.
99	N. 65°–70° E.	N. 20°	2–4	E. end Pleasant Beach; cut by 100; irregular.
100	N. 80° E.	Vertical	5	E. end Pleasant Beach; exposed long distance.
101	N. 75° E.	N. 5°	1	150′ S. of 100.
102	N. 80° E.	S. 5°–10°	3–4	About 250′ S. of 101.
103	N. 85° E.			25′ S. of 102; W. end of Sandy Beach; irregular.
104	N. 75°–80° E.	Vertical	3–4	N. side of Beach I.; probably cut by 105 and 107.
105	N. 85° E.	Vertical	10	N. side of Beach I.; exposed long distance.

106	N. 70°–80° E.	Vertical	4–5	70′ S. of 105; very irregular.
107	N. 85° E.	Vertical	3.5	50′ S. of 106 and 75′ N. of artificial harbor; faulted.
108	N. 80° E.	S. 5°	15	S. side of artificial harbor: branching.
109	E.–W.	N. 15°–20°	Irreg'lar	E. side of Beach I.; composite and branching.
110	N. 80° E.	N. 10°	1	Cuts 111 obliquely, both longitudinally and vertically.
111	E.–W.	Vertical	2.75	30′ N. of 112; interesting intersection by 110.
112	N. 82°–90° E.	Vertical	5–6	First dike N. of outlet of Little Harbor; branching.
113	S. 75° E.	N. 15°	5	First dike E. of outlet of Little Harbor.
114	E.–W.	S. 5°	2.5	40′ N. of 113. Dikes 113 to 118
115	N. 85° E.	N. 5°	5	18′ N. of 114. are all on shore
116	N. 80° E.	N. 10°	2	150′ N. of 115. E. of the outlet
117	N. 80° E.	N. 10	1	5′ N. of 116. of Little Harbor.
118	N. 80° E.	N. 10°	3	25′ N. of 117.
119	N. 80° E.	N. 5°	1–1.25	60′ N. of 118; 150′ from point; exposed 300′.
120	N. 80° E.	N. 5°	1	Point nearest Quamino Rock; exposed 200′.
121	N. 75° E.	Vertical	8	N. W. shore of Sandy Cove.
122	S. 75° E.	Vertical	6–7	Extreme end of Hominy Point.
123	N. 80° E	Vertical	6	South side of White Head.
124	N. 70° E.	N. 15°	3.5	In coarse granite on E. side of Deacon Bourne's Island.
125	Irregular.	Vertical	10	130′ S. of 124.
126	N. 70° E.	Vertical	3–4	75′ S. of 125.
127	N. 70° E.	Vertical	9	115′ S. of 126.
128	N. 70° E.	N. 15°	1.5	12′ S. of 127.
129	N. 77° E.	N. 10°	6	On Hog Rock in Cohasset Harbor
130	N. 70°-80° E.	Vert.–N. 10°	2-5	On shore W. and E. of Glades Hotel; coarsely porphyritic.
131	N. 80° E.	N. 5°	2.75	6′ N. of 130; near Glades Hotel.
132	N. 80° E.	N. 5°	11	About 200′ N. of 131; in diorite.
133	N. 80° E.	Vertical	3–4	About 90′ N. of 132; in diorite.
134	N. 82° E.	Vert.–N. 3°	4	30′ N. of 133; in coarse granite.
135	N. 80° E.	N. 10°	.5–.75	20′ N. of 134; in coarse granite.
136	E.–W.	Irregular	2.5	15′ S. of 130; E. of Glades Hotel.
137	N. 70° E.	N. 3°	3	30′ S. of 131; E. of Glades Hotel.
138	N. 75° E.	N. 10°	.5–.75	70′ S. of 135; on Strawberry Point.
139	N. 82° E.	N. 15°	3	About 100′ S. of 138.
140	N. 80° E.	N. 5°	2.75–3	About 25′ S. of 139.
141	N. 80° E.	Vertical	9	About 175′ S. of 140; irregular, branching.
142	E.–W.	Vertical	5.5–6	About 75′ S. of 141; branching.
143	N. 75° E.	Vertical	2	Headland E. of Strawberry Point.
144	N. 70° E.	Vertical	.5–3	About 300′ S. of 143; in old quarry.

145	N. 70° E.	Vertical	1–1.25	About 100′ S. of 144, in quarry; porphyritic.
146	N. 75° E.	N. 5°	1–1.5	Separated by short beach from 145.
147	N. 75° E.	N. 5°	2–3	Near 146.
148	N. 55° E.	N. 30°	8	150′ S. of 147; coarsely porphyritic and branching.

As a rule, the east-west dikes cut the shore ledges very obliquely; and in going eastward we cross the first system from north to south, and the second system from south to north. The outcrops begin in the rear of the Black Rock House, where 88 is readily recognized by its coarsely and distinctly porphyritic character. About 50 feet south of 88 is 89, a splendid dike, which can be traced almost continuously for fully 750 feet. About midway of the outcrop it is somewhat irregular and split up; and the well-preserved glacial striae upon it, and especially the freshness of an inscription bearing the date 1852, testify to the stable and resistant character of those diabase dikes which have, by deep-seated alteration, been largely changed to such almost indestructible species as epidote, chlorite, magnetite, and quartz. A little more than half a mile (2860 feet) from Forest Avenue brings us to 90, the largest of all the east-west dikes; and its outcrop is quite a center of eruption (Fig. 17). It cuts one of the porphyrite dikes (81) and is cut by no less than four of the north-south diabase dikes. The small dikes (90*a* and 91) are probably branches of 90. The magnetic dike (94) is so highly charged with magnetite as to make the compass observations quite unreliable. It not only cuts 85 and 86, but just before entering the sea is cut by 156 of the third system, which also cuts 95. The next three dikes of this series (96, 97, 98) follow in regular order and bring us to Walnut Angle or the eastern end of Cohasset Rocks. No dikes have been observed in the ledges on Pleasant Beach; but near its eastern end we strike 100, which can be traced the entire length of the headland, trending just north of the extreme north end of Brush

Island. In like manner, 103, on the east side of this headland, is exactly in line with a large dike near the southern end of Brush Island.

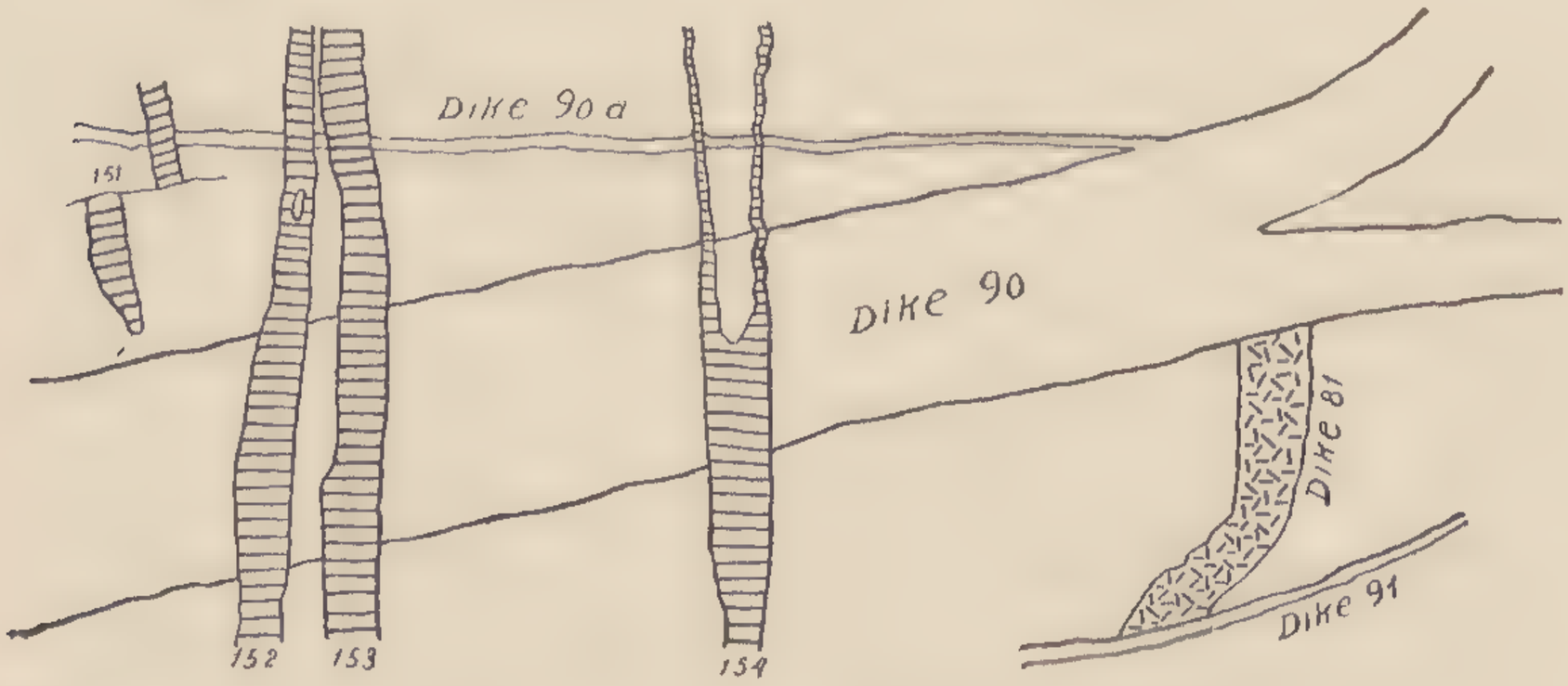


FIG. 17.—PLAN SHOWING A GROUP OF INTERSECTING DIKES ON THE COHASSET ROCKS. SCALE, 1 INCH = 50 FEET.

Crossing Sandy Beach, we come at once, on the north side of Beach Island, to 104 and 105, which can be traced for long distances, the latter enclosing, near the eastern shore, a long narrow mass of granite. The second dike beyond (107) is slipped about twice its width. The large dike south of the artificial harbor divides eastward into two unequal branches separated by from 8 to 10 feet of granite; and 15 feet north of it is a one-foot branch. The composite dike (109) on the east side of Beach Island is near the contact of the coarse typical granite and the mixed granite and diorite. The intersection of 111 by 110 (Fig. 18) is a clear case of the confusion of the first and second systems. The intersection is very oblique, extending over 20 feet along 111. Immediately north of 110 is an unenumerated six-inch dike. The next dike (112) is a fine and instructive example of a branching fissure, and shows flow-structure parallel with the walls.

The dike on Hog Rock (129) is exposed again in the re-entrant angle of the shore south of Strawberry Point. The next dike (130) is beautifully porphyritic, with large clustered

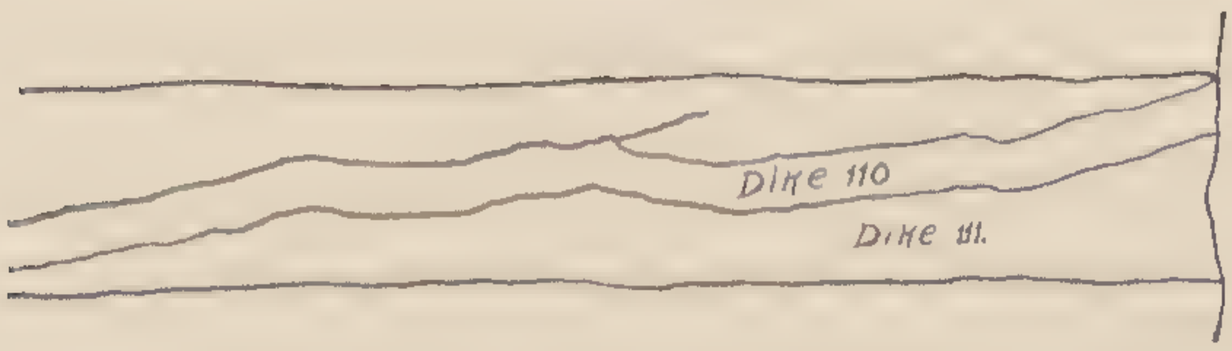


FIG. 18.—PLAN SHOWING THE INTERSECTION OF TWO DIKES ON THE EAST SIDE OF BEACH ISLAND.
SCALE, 1 INCH = 8 FEET.

crystals. It outcrops west of the hotel, east of the hotel, and then, after some faulting and branching, on the east side of Strawberry Point. The remaining dikes on Strawberry Point (131–142) are easily found and identified by taking the ledges in order from west to east, one of them (135) cropping on three distinct ledges.

North–South Dikes.

No.	Trend.	Hade.	Width in feet.	Remarks.
149	N. 10° W.	Vertical	3–4	On Cohasset Rocks, 400′ E. of Black Rock House.
149*a*	N.–S.	Vertical		In the valley immediately E. of the Black Rock House; imperfectly exposed.
150	N. 5°–10° E.	Vertical	2–3	On Cohasset Rocks; cuts 80 obliquely.
151	N.–S.	Vertical	3–4	Interrupted and faulted; cuts 90.
152	N.–S.	Vertical	3–6	Cuts 90; irregular.
153	N.–S.	Vertical	6–7	Cuts 90; unites with 152.
154	N.–S.	Vertical	7.5	Cuts 90; branching northward.
155	N. 8° W.	Vertical	3–3.5	About 200′ E. of 154, on Cohasset Rocks.
156	N. 5°–10° E.	Vertical	2	On Cohasset Rocks; cuts 94 and 95.
157	N. 15°–45° E.	S. E. 30°–45°	2–8	On Hominy Point, near White Head.

On the short, stony beach immediately east of the Black Rock House there are traces of several — at least three and possibly more—dikes (149*a*) of this system, recalling the composite dike of the Nantasket area (66). The last of the north-south dikes

(157) is the only really doubtful one. This is the dike shown in Fig. 19. In tracing it across the ledge to the mainland, its easterly trend, hade, and thickness are all greatly increased; and it would, perhaps, be best to class it as a highly aberrant member of the first system.

FIG. 19.—DIKE 157 CUTTING A LEDGE OF GRANITE, NEAR WHITE HEAD, ON HOMINY POINT, COHASSET.

SEQUENCE OF EVENTS RECORDED IN THE NANTASKET LEDGES.

It is unnecessary to review or summarize farther the evidence supporting the conclusions that have been reached in the preceding pages concerning the succession of the beds of conglomerate and the flows of lava; but we may fitly close this section with a general statement of the geological history of Nantasket so far as it is recorded in the hard rocks. The granite, with the associated diorite and felsite, is the fundamental rock in this part of the Boston Basin; and it had, apparently, been exposed to erosion for a long time before the basal conglomerate was deposited over it. The character of this conglomerate

is, however, a sufficient indication that outflows of lava and, very probably, the deposition of conglomerate had already begun in the deeper parts of the basin; and we may fairly suppose that both conglomerates and lavas older than any exposed in southern Nantasket underlie at a great depth the northern part of the peninsula. Eventually the slow subsidence of the land then in progress carried the shore-line over and beyond the Nantasket area, and the so-called basal conglomerate was formed upon the uneven and fissured surface of the granite. This conglomerate had attained a maximum thickness of perhaps 50 feet, when the first flow of melaphyr was spread over it. This was probably originally an ordinary compact, black lava; but through subsequent alterations it has become greenish and purplish, compact and jaspery. The lava-flow being submarine, the sedimentary process was uninterrupted; and the uneven and scoriaceous upper surface of the melaphyr was slowly covered by the second conglomerate, which is largely composed of debris derived from the melaphyr, and like this melaphyr is especially characterized by the segregations of red jasper. When the second conglomerate had attained approximately the same thickness as the basal conglomerate, a flood of more acid lava (porphyrite) was spread over the sea-bottom to a depth of from 50 to possibly more than 100 feet; and all the porphyrite in the Nantasket area probably belongs to what was once one continuous flow, increasing in thickness eastward, or toward the vent from which it issued. Over the porphyrite was gradually accumulated the third conglomerate to a thickness of from 50 to 100 feet or more, but terminated at last by a comparatively thin flow of highly basic and vesicular basaltic lava, which is recognized now as a typical green and amygdaloidal melaphyr. The fourth conglomerate, with a thickness of from 20 to 30 feet, separates this second melaphyr from the very similar third melaphyr. The latter consists, however, of two flows, having an aggregate thickness of from 40 to 50 feet. Once more the beach conditions prevailed,

and the fifth conglomerate was formed. When the volcanic activity was again renewed over this area, the eruptions were, for the first time, partly of an explosive character, forming, as the Atlantic Hill section shows, beds of tuff alternating with beds or flows of compact and brecciated melaphyr. This marks the culmination of the volcanic energy, flow succeeding flow, until they attained an aggregate thickness of several hundred, possibly five hundred, feet. This series of eruptions completes the conglomerate and melaphyr series as now developed in the Nantasket ledges; but on the extremity of Rocky Neck we find evidence that the great melaphyr was finally covered by a sixth bed of conglomerate, and that by a flow of green, amygdaloidal melaphyr resembling the second and third sheets of that rock.

The volcanic energy finally died out; and these alternating sheets of conglomerate, melaphyr, and porphyrite were probably covered by a great thickness of conglomerate and sandstone without interbedded lavas. But of this upper conglomerate series there are now no visible traces in the Nantasket Peninsula, although Harding's Ledge, as already explained, affords some evidence that it underlies the middle part of the beach, in the vicinity of Strawberry Hill. As the subsidence progressed and the water became deeper and the shore more remote, the deposition of the coarser fragmental rocks over this area gradually ceased, the conglomerate changing through sandstone to slate, which, we may fairly suppose, underlies almost the entire peninsula north of Atlantic Hill, and has a thickness of several hundred, possibly a thousand, feet. The deposition of the slate probably occupied a much longer time than that of the conglomerate series; but it was finally terminated by the period of disturbance during which the sediments of the Boston Basin were strongly folded, faulted, and elevated to form dry land. It is to this geological revolution that we owe nearly all those structural complexities which make the stratigraphy of the Boston Basin such a difficult problem. This was also

probably a period of intense igneous activity, the numerous dikes of diabase traversing the ledges of Nantasket and other parts of the Boston Basin appearing to date from this time. The dikes were probably, in many cases, the feeders or channels of supply of effusive eruptions; but these surface lavas of every form, not being protected by later sediments, have, at least in in the Nantasket district, been long since completely swept away by the agents of erosion, which during all subsequent time have worked unceasingly and so efficiently that not only have these ancient volcanoes been destroyed but the very foundations on which they stood. In southern Nantasket the entire thickness of the slate series and probably, on the average, half of the conglomerate series have been removed; and over broad areas erosion has exposed the original granite floor or cut deeply into it.

AGE OF THE NANTASKET ROCKS.

Up to the present time no fossils have been found in the Nantasket ledges. It is, of course, improbable that any ever will be found in the conglomerate and volcanic series; but we may reasonably entertain the hope that the slate ledges will yet afford us some clue to their geological age. Fragments of a somewhat calcareous slate have been observed in the drift of Strawberry Hill, and suggest the possibility that beds of impure limestone (of organic origin, if not actually fossiliferous) underlie the northern end of the peninsula. It seems impossible to feel quite sure that the hard massive slate on the railroad, northwest of Rockland Hill, which has been referred provisionally to the bed of tuff outcropping at the base of Atlantic Hill, is not really an isolated exposure of the Cambrian slate of Braintree and Weymouth. The Weymouth beds are now referred by Walcott, provisionally at least, to the Lower Cambrian; and the Braintree beds to the Middle Cambrian[1]. The granite and diorite are undoubtedly here, as elsewhere in the Boston

[1] Tenth Ann. Report U. S. Geol. Survey, p. 567.

Basin, younger than these Cambrian strata; and it is perfectly clear that the conglomerate and melaphyr series is newer than the granite, and therefore distinctly more recent than the Middle Cambrian. They are quite certainly Paleozoic, but whether as late as the Carboniferous strata in the Narragansett Basin is at least doubtful. The conglomerate and melaphyr and newer slates of the Nantasket area may be safely correlated with the same rocks in other parts of the Boston Basin; and it is hoped that, before the revision of the geology of the basin is completed, evidence will be forthcoming which will finally and definitely settle the question as to the age of these strata; but for the present the problem must be regarded as unsolved.

In January of this year (1892), Mr. T. A. Watson found on Pleasant Beach, Cohasset, a smoothly rounded and evidently water-worn bowlder, between five and six inches in diameter, of a highly fossiliferous, compact, red (ferruginous) limestone. The fossils appear to belong wholly to two species, which have been identified by Mr. C. D. Walcott[1] as the two Lower Cambrian types *Straparollina remota* Billings and *Hyolithes communis* Billings. Although Mr. Watson was unable, after the most thorough search, to find a second specimen of this limestone on the Cohasset shore, its Cambrian age made it seem highly probable that it had been derived from some point within the Boston Basin, and possibly within the Nantasket and Cohasset district, thus encouraging the hope that it would yet afford us the desired clue to the geological age of the Nantasket strata. But this hope has been dispelled; for Mr. Watson has recently found several water-worn fragments of precisely the same kind of limestone, holding the same fossils, but not quite so abundantly, on the beach at Bass Point, Nahant. We can no longer doubt that this rock is a part of the Cambrian limestone of Nahant, although representing a more ferruginous and more conspicuously fossiliferous bed than any now exposed on that peninsula; and the Cohasset specimen must be regarded as a solitary glacial erratic.

[1] Proc. Biological Society of Washington, VII., 155.

THE SURFACE GEOLOGY OF NANTASKET AND COHASSET.

As a starting point for the surface geology of this district, including both its glacial and post-glacial history, we must accept the preglacial peneplain, the evidence for which has been presented in sufficient detail in the general description of the topography (pages 5 to 7). The Mesozoic and Cenozoic eras are, apparently, unrecorded here, except in the erosion of the hard rocks. But, while it is to these long geological cycles that we must refer the removal of a great thickness of stratified rocks from this area, and the wearing down to the base-level of the hard granitic rocks, lavas, and conglomerates, the rugged contours presented today by the preglacial peneplain undoubtedly date chiefly from the marked elevation of the land which, it is probable, ushered in the great ice-age. On account of the intense hardness of the rocks, these deeply incised lines were only partially effaced by the powerful abrasive action of the ice-sheet; but, as we have already seen, they are to a large extent obscured or concealed by the non-lithified deposits of glacial and post-glacial origin.

The principal events recorded in the surface geology, since the development of the preglacial peneplain, are: (1) A considerable elevation of the land at the beginning of the glacial epoch. The elevation was, probably, a principal cause of the subsequent glaciation, and is proved by the deeply eroded character of the peneplain. (2) Long-continued glaciation, during which the divided peneplain was strongly eroded and the ground-moraine or bowlder-clay accumulated irregularly upon it, chiefly, at the last, in the form of drumlins. (3) A marked depression of the land, accompanied by the final melting and retreat of the ice-sheet, and the accumulation, either in the sea or in temporary lakes and streams, of the ex-

tensive deposits of modified drift. (4) A slight re-elevation of the land immediately after the disappearance of the ice and, probably, during the formation of the modified drift. The elevation is proved in other parts of the Boston Basin by the occurrence of clay beds above sea-level, and generally, it is believed, by cut terraces on the drumlins and marine deltas of sand and gravel. (5) The development of the modern shore, including the growth of the beaches and marshes, accompanied by a slow movement of subsidence.

There remains now, in order to complete this paper, simply the task of setting forth more fully the tangible and material facts upon which the foregoing statements rest, taking up the topics, so far as possible, in the chronological order.

DRUMLINS, GLACIAL STRIAE, AND BOWLDERS.

The unmodified drift or till of this district, so far as it now exists above the sea and is not covered by the modified drift, occurs almost wholly in more or less typical drumlins. The positions, outlines, heights, and names of these are indicated on the general map, so far as they have been determined.

Rockland Hill, however, is only an incipient drumlin, and might be more properly classed as a lenticular slope of till. Telegraph Hill, World's End, Planter's and Pine Hills, Turkey Hill, Bear Hill, and others are examples of composite drumlins; what were originally separate accumulations of till becoming more or less perfectly united by their continued growth.

As the map shows, the longer diameters of the drumlins have without exception a strong easterly trend, varying between south-southeast in the southern and east-southeast in the northern part of the district, and agreeing closely at all points with the glacial striae on the ledges.

The following observations on the directions of the striae embrace the extreme range and are sufficiently numerous to show

the normal courses. It is very obvious that in crossing what is now the Nantasket Peninsula the ice was strongly influenced by the eastward trend of the main valley of the Boston Basin, being held to this course partly, perhaps, by the eastward slope of the ground and the proximity of the sea in that direction, and partly by the continuous barrier of granite 200 feet or more in height presented by the south shore of the harbor. But when the ice had escaped from this influence by flowing out of the harbor into the bay, or by scaling the ledges to the peneplain of Cohasset, it resumed more nearly its normal south-southeast trend, as shown by the drumlins and the glacial striae along the Cohasset shore.

Directions of Glacial Striae.

Slate ledge south of Thornbush Hill.	S. 72°–75° E.
Northeast base of Atlantic Hill.	S. 43° E.
Double dike on Little Gun Rock.	S. 37°–47° E.
Dike 13 in Green Hill Ledge.	S. 80° E.
Slate on the railroad south of Nantasket Station.	S. 35°–40° E
East side of the bay, near the railroad.	S. 35°–40° E.
North base of East Porphyrite Hill.	S. 17°–50° E.
West end of Granite Plateau.	S. 53°–57° E.
East side of Rocky Neck.	S. 43° E.
West side of Rocky Neck.	S. 41° E.
South side of Weir River Bay.	S. 40° E.
Jerusalem Road, south of Straits' Pond.	S. 36° E.
" " near Green Hill Beach.	S. 80° E.
Cedar Street, Cohasset.	S. 30°–35° E.
West side of Little Harbor.	S. 22°–25° E.
Cohasset Rocks, east of GreenHill Beach.	S. 70° E.
" " one fourth mile east of beach.	S. 46° E.
" " near Pleasant Beach.	S. 40° E.
Beach Island, near the artificial harbor.	S. 32°–35° E.
" " near Pleasant Beach.	S. 25°–30° E.
Strawberry Point, Scituate shore.	S. 25° E.
Scituate shore, south of Strawberry Point.	S. 25° E.

Doubtless the most interesting feature presented by the composition of the till is the occurrence of fossil shells in some of the drumlins. Mr. Warren Upham has noted[1] the finding of fragments of shells in the sea-cliffs at several points about Boston Harbor, including the northern member of Tele-

[1] Proc. B. S. N. H., XXIV., 127–141.

graph Hill and Sagamore Head in the Nantasket area. He has also called attention to the fact that, so long ago as the Revolutionary War, a fort was built on the top of Telegraph Hill, and a well was dug inside the fort of which the commander, Gen. Benjamin Lincoln, wrote as follows[1] : "There is a large fort on the E. Hill, in which there is a well sunk 90 feet, which commonly contains 80 odd feet of water. In digging the well, the workmen found many shells, smooth stones and different stratas of sand and clay similar to those on the beach adjoining to the hill. These shells and appearances were discovered from near the top of the ground to the bottom of the well."

Of more than thirty species of shells collected by different observers from the till of the Boston Basin, Mr. Upham has, in a hasty examination, found but three — *Venus mercenaria* (the round clam or quahaug), *Cyclocardia borealis*, and *Cliona sulphurea* (a boring sponge)—in the section at the north end of Telegraph Hill; and traces of the round clam, which is by far the most abundant species in all the sections, in Sagamore Head. More recently, by careful searching, with the assistance of Mr. H. D. Card, I have found the shells in the eastern scarps of Point Allerton Great Hill, and Strawberry Hill; and have extended the list of fossils known to occur in the till of the Nantasket Peninsula to eleven species, as follows :—

List of Species in the Nantasket Drumlins.

Species.	Telegraph Hill.	Point Allerton.	Strawberry Hill.
Balanus (*sp. ?*).	*	*	
Tritia trivittata, Adams.		*	
Ilyanassa obsoleta, Stimp.	*		
Crucibulum striatum, Say.	*		
Buccinum undatum, Linné.		*	
Mya arenaria, Linné.	*		
Venus mercenaria. Linné.	*	*	*
Cyclocardia borealis, Conrad.	*	*	*
Astarte undata, Gould.	*	*	*
Scapharca transversa, Say.		*	*
Cliona sulphurea, Verrill.	*	*	*

[1] Geographical Gazetteer of the Towns in the Commonwealth of Massachusetts, 1875, p. 56. (Only a small part of this work was published.)

I have failed to find even the slightest trace of shells in any of the drumlins south of Nantasket Beach. This is an instance, however, where negative evidence is of very little value, the apparent presence or absence of shells depending very largely upon the character of the exposure. A deep section is usually essential; for, as Mr. Upham has explained, the shells are very likely to have been dissolved out of the upper, oxidized or weathered layer of the till. It is probably for this reason that they are not found in the shallow sections afforded by Point Allerton Little Hill, Little Hog Island, White Head, World's End, and Planter's Hill, as well as all the inland drumlins. We may reasonably hope, however, that shells will yet be found in Green Hill and on Bumkin Island. That shells actually occur in the drumlins of Cohasset we have satisfactory evidence in the fact, to which my attention has been called by Mr. H. W. Nichols, that fragments of the round clam were found by Mr. Titus Burbank some years ago in digging a well near the summit of James Hill, northeast of Scituate Pond. The well is 45 feet deep; and the shells were observed only near the bottom. They cannot, therefore, be referred to any post-glacial source.

Although shells are now so generally wanting in the buff or oxidized till, evidence of their former existence is afforded by the calcareous material which may, in certain cases, be detected in the till. This evidence is especially clear in the buff till of Telegraph Hill. The carbonate of lime has, in part at least, been dissolved and segregated, locally but firmly cementing the till, and forming in the finer parts regularly rounded concretions, from a fraction of an inch to several inches in diameter, which are sometimes attached to the flat surfaces of the large stones or bowlders. These nodules effervesce freely with acid, and no other source of the carbonate than the shells is apparent.

Mr. Upham has correctly explained the shells in the till, which are always in a fragmentary form, as having inhabited the bottom of Boston Harbor before the coming of the ice-sheet,

by which they were gathered up and incorporated in the till; and he has shown that some of the species, at least, like the round clam, are now found only in more southern waters, indicating that the sea in this vicinity just before the glacial epoch was warmer than at the present time. The shells are also of special interest as proving not only that Boston Harbor was in existence in preglacial times, for otherwise we could not know but that this basin was above sea-level before as well as during its occupation by the ice-sheet; but they also show that the harbor has now approximately its preglacial outlines and hence that the sea has regained, on this coast, very nearly its preglacial level.

The peneplain, as already stated, and especially when we make an allowance for the glacial erosion upon its surface, proves that this coast is now one hundred feet or more above its preglacial level. But this greater elevation is off-set, so far as the harbor is concerned, by the excessive erosion which, being a valley in comparatively soft rocks, it suffered in glacial and especially in immediately preglacial times.

Although the fragments of shells are unquestionably the most interesting feature of the till observed in Nantasket and Cohasset, other components of more normal character—the ordinary stones and bowlders—demand brief mention. No particularly striking instances of glacial transportation have been noted. The till of the Nantasket Peninsula, as may be most readily seen in the marine sections of the drumlins, consists very largely of fragments of slate, which is undoubtedly the underlying rock not only of this peninsula but of the main part of the harbor to the northward. Bowlders of conglomerate are not wholly wanting north of Atlantic Hill, but they are so few and small as to prove that it can occur only very sparingly, if at all, in the harbor area or beneath the extensive drift-deposits north of the harbor. In fact, pretty much all of the conglomerate in the till north of the Nantasket ledges might be referred with considerable probability to the known exposures of that

rock in Medford, on the extreme northern margin of the Boston Basin, or at least to the probable eastward extension of those beds beneath the drift; although the strong easterly trend of the glacial movement in the harbor allows us to regard the prominent conglomerate ledges in the central part of the basin as a possible source of some of the conglomerate erratics in the Nantasket Peninsula and Cohasset. In the Nantasket drumlins, granitic rocks, felsites, quartzite, etc., from the high land north of the Boston Basin, form a small but very obvious or noticeable fraction of the till, and in some cases exhibit lithological peculiarities enabling us to refer them to the parent ledges, as in the case of the bright red felsite from Saugus Centre. A portion of what might be mistaken for conglomerate is brecciated felsite, and another portion is brecciated or pebbly slate. Over the granitic area of Cohasset and Scituate, as a matter of course, the crystalline rocks predominate in the till, and the slate, which does not bear glacial transportation well, is subordinate, except, perhaps, in the finest part of the till. There is, however, among the larger masses or fragments in the till, a quite liberal sprinkling of both melaphyr and conglomerate from the Nantasket ledges. These are especially noticeable along the shore, the number and average size, with occasional exceptions, diminishing rapidly as the distance increases.

The surface distribution of the larger bowlders indicates that they are not equally abundant in all parts of the till; for while the majority of the drumlins are remarkably smooth, presenting on the surface but few bowlders larger than those to be seen in the stone walls, others, like Booth Hill in Scituate, are, at least on certain slopes, thickly strewn with masses from three to eight feet or more in diameter. The bowlders are, in some cases at least, clearly most abundant along those lines where the till has been eroded by standing or running water and which may thus be regarded as in some sense ancient shores or

channels, resembling the modern shore in this respect; or over areas where there is at least evidence that the till has been subjected to the sorting action of water and the finer materials removed. It is reasonable to suppose that the bowlders are most abundant in the lower parts of the drumlins, and in general where the till is thinnest, as may be observed at many points over the rocky peneplain of Cohasset; and it is certainly not improbable that, as suggested to me by Mr. Upham, this is owing, not wholly to the fact that the source of the bowlders is near at hand, but partly to an actual combing of bowlders out of the till or ground moraine as it was swept past the ledges by the movement of the ice, the ledges thus serving as gathering points for bowlders.

An occasional bowlder merits special attention on account of its size; and some of these are rather striking also in their situations. As might be expected, the largest erratics consist almost exclusively of granite, the most massive and resistant rock of the region. One of the most impressive examples observed in the Nantasket-Scituate area is the block of granite on Booth Hill, in Scituate, known as Hatch's Rock (Fig. 23). It is very regular in form, approximately twenty feet square with an average height above the ground of at least ten feet. It stands on the summit of the hill and some fifteen feet above a broad level terrace or platform. Near the eastern base of Booth Hill, on the grounds of Mr. Silas Peirce, is Toad Rock, a block of diorite about twenty feet long resting on a local deposit of modified drift.

A granite bowlder about twenty feet long, twelve feet wide, and ten feet high lies in the woods close on the south side of Beechwood Street, about one mile northwest of Beechwood Village, with several others nearly as large near it; and east of the Village a block of granite which is approximately a ten-foot cube lies on the west side of Bound Brook, a few rods south of the street; while in the rocky woods south of Scituate Hill may be found a striking example of a large bowlder which has been disrupted by the action of the frost.

In a walk along the shores of Nantasket, Cohasset, and Scituate, one observes occasional large bowlders, sometimes local and sometimes traveled or truly erratic, but the only one that need be specially mentioned is an angular block of coarse, massive, pinkish granite, one among a large number of smaller masses, on the eastern shore of the Glades, in Scituate, and nearly opposite the Osher Rocks. It is about twenty-five feet long; but being of precisely the same lithological character as the neighboring ledges, it would, perhaps, escape particular notice, except for its position, being supported by smaller bowlders and the ledge in such a manner that when the tide is out one can pass under it from one side to the other. The fact that it maintains this insecure position, although exposed to the full force of the breakers, testifies to its great weight.

The best example, however, of a perched block, and one of the largest bowlders in Cohasset, is the mass of granite on the estate of Mr. Edward Wheelwright west of Little Harbor, which has long been known as Tittling Rock (Fig. 20). Going north from Cohasset Village on Jerusalem Road, we come in about half a mile to the residence of Mr. Wheelwright, whence a private road runs nearly due west for a considerable distance through beautiful rocky woodland, bringing us, when about two thirds of a mile from the highway, to Tittling Rock. The bowlder, which lies close to the road on the south, is a rude and somewhat oblique parallelopipedon measuring approximately 20 feet in extreme length (north-south), 12 feet in breadth, and 12 feet in greatest height. Its location is almost the highest point in this part of the peneplain, probably 100 feet above the sea. It rests upon a low, glaciated ledge of granite sloping gently to the north, seeming to lie in a shallow depression or glacial trough; and the actual base or supporting surface is not more than six feet long and from two to three feet wide. But although seemingly so nicely poised, considerable force would probably be required to disturb it; and it is not properly a rocking stone.

FIG. 20 —TITTLING ROCK, COHASSET.

On the northwest slope of Telegraph Hill, just above the junction of the main hill with the lower, flat-topped part, is a block of coarse granite about fifteen feet in diameter and from six to seven feet high above the ground. A very similar block rests in a similar position on the north side of Strawberry Hill. It is about fifteen feet square and eight if not ten feet thick. Two bowlders of granite, essentially similar to these, are similarly situated on the northern slope of Otis Hill, in Hingham. The occurrence of these isolated blocks on the northern aspects of the hills, and at approximately the height of one of the principal sand plains, is certainly suggestive of their transportation by floating ice rather than the ice-sheet; and it appears necessary to regard them as having been derived from the granite ledges north of the Boston Basin, the nearest possible source of granite of this character, in the direction of glacial movement, being twelve to fifteen miles distant.

GLACIAL POTHOLES.

Four years ago, my attention was first called by Mr. T. T. Bouvé to the existence of a fine series of glacial potholes on Cooper's Island in Little Harbor, Cohasset, and I had the

pleasure a little later of examining the locality in company with him and Mr. Warren Upham. In the following year Mr. Bouvé published a full account of the potholes,[1] from which the greater part of the following description is taken, together with the illustrations (Figs. 21 and 22).

FIG. 21.— POTHOLE, COOPER'S ISLAND.

Cooper's Island, so-called, is the peninsula consisting of granite ledges and salt-marsh which extends into Little Harbor from the west side. The eastern end, which reaches nearly to the middle of the harbor, is an approximately north-south ridge of granite one fourth of a mile long and from 15 to 25 feet high. This ridge is divided transversely near the southern extremity by a short stretch of grass land; and it is near the

[1] Proc. B. S. N. H., XXIV, 219–228.

southern end of the main ridge, on the east side and quite close to the water that the potholes occur. The most southerly and most perfect holes are on the north side of a slight indentation of the rocky shore and may be readily found when the tide is out (Fig. 21). Of the lowest and best preserved of these (No. 1) the bottom is still intact and perfect, holding water to a depth of 21 inches and having a well-defined rim just at the surface of the water. The diameter at the rim is $25\frac{1}{2}$ inches; below the rim, 30 inches. Above this rim the whole southern side of the hole is wanting; but on the northern side the rock is smoothly concave and the characteristics of the pothole are plainly discernible for a height of four feet, with a breadth of from three to four feet, making the total depth about six feet. The whole has the appearance of a large, imperfect or one-sided pothole with a smaller and perfect pothole in the bottom of it. Exterior to this pothole, the tide sinks below the level of its bottom, but at high tide all is covered.

The second pothole has its bottom three and one half feet above that of No. 1; and their centers are three feet apart horizontally. The whole southern side of this hole (No. 2) is wanting and water can now stand in it only to the depth of about two inches. Above the bottom, the granite is smoothly concaved for a breadth of three feet and a height of five feet; and this hole, when entire, was evidently about as large as the first. The slope of what remains of the walls of these holes shows, apparently, that the flow of water over the rocks was from the west and northwest. Of the third pothole there is but little to be said, except that it is small and shallow. It is about five feet above the bottom of No. 2, still in a northwest direction; and there may be traced from it in the same general direction a narrow water-worn channel about six feet in length. The high-tide mark is about midway between the second and third potholes.

It is quite obvious that these potholes were once entire. Their sharply-defined vertical edges are seen to coincide with

one well-marked joint-plane sloping steeply to the south; and the southern sides of all three of the holes have, apparently, been carried away, by the removal of a single large joint-block of the granite. Since this block appears to have been torn away bodily, leaving an angular, unglaciated surface, and no trace of the block itself can be seen in the vicinity, we may fairly regard its removal as the last work accomplished by the ice-sheet on the lee side of this ledge.

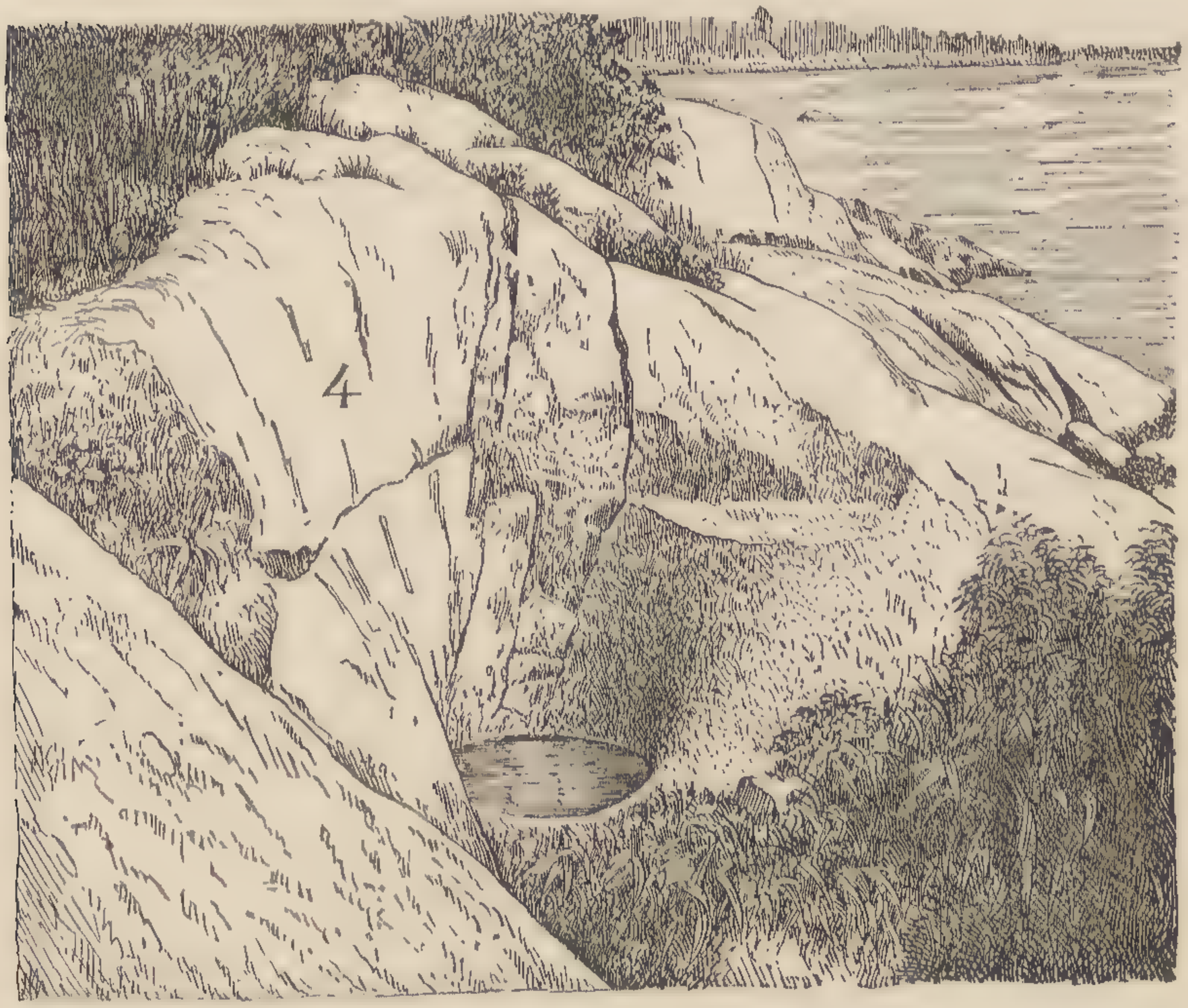


FIG. 22—POTHOLE, COOPER'S ISLAND.

The fourth pothole is or was the largest of all, and hence has been commonly called the "Well." Passing over the rocky elevation in a northerly direction, it may be found about a

hundred feet distant from the others; and it is a little farther than the others from the shore, its bottom being about four feet above high tide (Fig. 22). The bottom of this hole, which is still entire, so as to hold water to a depth of about one foot, is cut in the solid granite at the base of a small scarp. It is somewhat oval in form, the horizontal diameters varying from two feet ten inches to four feet. The ledge rises abruptly nine feet from the margin of the Well and ten feet from its bottom; and the Well itself was probably as deep at least as ten feet, the curvature and wearing of the rock clearly showing this. The beautifully rounded and water-worn form of the granite on the southeast side of the Well, above the water, is a plain indication, however, that it has not been entire on this side since the water ceased to swirl through it. On the north side the concave wall is vertical or slightly overhanging; but on the west side the wall is widely flaring, receding upwards in such a way as to indicate that the water entered at this point, the Well agreeing in this respect with the group of potholes (1 to 3). It seems probable that the pothole was entire in its early stages; but as it increased in size the outer or lee wall was either worn through or carried away bodily by the ice, after which the rush of water continued long enough to develop the graceful contours of its natural exit, as shown in the figure.

Besides these four potholes, there are other depressions which are evidently incipient or embryo potholes. A linear group of these may be observed about twenty feet north of, and parallel with, the southern series (1 to 3). The upper one is shallow, like the bowl of a spoon, about a foot across, showing, extending from it, a water-worn channel sloping easterly about ten feet to the brink of the ledge, connecting the first depression in its course, with two others of similar form; while on a lower surface there is a larger depression just where the water from the first might descend.

Considering the shallowness of the entire portions of all the

potholes, and the probability of their visitation by generations of both the Indian and the white man, it is not surprising that nothing of their contents is left in or about them. There is, however, one rounded stone in the possession of Mr. Charles S. Bates, the owner of Cooper's Island, which tradition states to have been taken from the deepest pothole (No. 1). It is a smoothly rounded and nearly spherical ball of granite about four inches in diameter,—a typical pothole bowlder; and there seems to be no reason to question the truth of the tradition.

On one of the higher ledges south of Little Harbor and Beach Street, and near the village, there is a smooth hollow in the granite, about a foot across and nine inches deep, which, from its form, has been called the "Devil's Armchair." Although not well-defined, it is clearly a small pothole; and in this instance, as in others, an apparently water-worn channel extends east-southeast on the rather abrupt slope of the ledge for several feet, ending in another and smaller hole. During the past year I have discovered still another pothole. This is on Cohasset Rocks, immediately behind the Black Rock House, on a bare surface of granite sloping down into the sea, and only two or three feet above the high-tide level. It is a smoothly-worn and sharply-defined basin, somewhat pear-shaped in outline, and measuring 41 by 33 inches in maximum length and breadth, the major axis trending about S. 15° W. It holds about six inches of water, but the depth below the well-defined rim varies from 6 to 18 inches, being shallowest on the side toward the sea.

The potholes of Cooper's Island, although on the shore, do not directly face the sea, and the Well, especially, is quite shut in by the granite ledge on the seaward side, as the cut shows. They are also partly above the high-tide level; and the lower ones are bathed only by the quiet waters of Little Harbor. If the sea were high enough to sweep over Beach Island and the other barriers between Little Harbor and the Atlantic, the potholes would be completely submerged and so still beyond the

reach of the surf. In short, both the situation and the forms of the potholes make it impossible to regard them as in any sense the product of marine erosion. It is equally clear that no ordinary or surface river ever flowed over these ledges. We are forced, therefore, to ascribe their origin to the action of glacial streams. But here the question arises as to whether they have probably been formed by subglacial rivers rushing along over the ledges, or by streams which, flowing over the surface of the ice-sheet, plunge through crevasses to the solid rocks below. Such a waterfall in the ice is called a *moulin* or glacial mill; and since the crevasses must often be of great depth—hundreds or even thousands of feet—these glacial mills are generally recognized as the most efficient of all agencies in the formation of potholes. Subglacial streams, it is believed, must usually, like ordinary rivers, follow the depressions of the rocky surface; while *moulins*—the chief source of the subglacial stream—may strike the ledges with resistless force at almost any point, and especially on the crests and southeastern or lee slopes of prominent ledges and ridges, where the conditions are most favorable for the formation of profound crevasses. A strong presumption is thus created in favor of the glacial mills as a cause of the potholes of Cohasset. One difficulty, however, still remains. As the ice-sheet moves continuously forward, carrying the crevasses and *moulins* with it, how is it that the potholes escape elongation in the direction of the movement? Of course a *moulin* cannot move forward indefinitely, but only until a new crevasse is formed behind the one through which the water first fell, a few feet or yards at the most; and the *moulin* then returns to its starting point. But why do the potholes not show even this small amount of elongation?

Mr. Bouvé has discussed this point in the following words[1]: "It has, indeed, been thought strange that, as the ice moved continuously on, the holes were not found generally elongated

[1] Proc. B. S. N. H., XXIV, 224.

in the direction of the movement of the glacier rather than circular. Such thought, however, is only consistent with the presumption that the holes were made just where the water first fell upon the rock surface below. Far more reasonable is it to suppose that the holes were formed somewhat distant from this place, where the masses of rocks borne by the waters found a lodging in some depression and there by rotation worked out the potholes. The ice might move on and the waters descend through the *moulin* far from where they first fell, yet continue their flow in the same direction as at first and go on with the work of rotating the contents of the hole through a whole season. In such case there could be, of course, no reason to expect the elongation." In explanation of potholes in close proximity to others and yet seemingly independent, as in the case of the Well, Mr. Bouvé says: "Observation upon Alpine glaciers shows that as a crevasse is carried forward by the general movement of the ice it closes. Subsequently a new one is formed just where in relation to the land at the margin of the glacier the former one existed; and the waters again descend upon the rock surface near where they before fell, but not often, probably, in exactly the same place; and thus potholes are formed contiguous to each other and yet far enough distant to make it evident that they were not produced by the same flow of water." This is undoubtedly a true explanation of many glacial potholes; and its weakest point, as applied to most of the potholes of Cohasset is that it requires the water to flow up over instead of around the prominent ledges.

Mr. Upham has suggested a different explanation. He says[1]: "The time of the excavation of these glacial potholes was probably the early part of the epoch of glaciation, when the ice-sheet was being formed upon the land by snow-fall. Upon any hilly country the ice must have attained an average depth somewhat exceeding the altitude of the hills above the adjoining lowlands before any general motion of the ice-sheet could

[1] Proc. B. S. N. H., XXIV, 226-228.

begin. During this process of slow accumulation of the ice-sheet, the summer melting upon its surface would produce multitudes of rills, rivulets, and brooks, which might unite into a large stream, and this, pouring through a crevasse and melting out a cylindric *moulin*, might fall a considerable depth to the bed rock, perhaps one or two hundred feet or more upon an area so moderately uneven as Cohasset, while yet the ice-motion, though sufficient to permit the formation of the crevasse, might not have gained a definite current to carry the crevasse, *moulin*, and water-fall away from the spot where they were first formed. We may thus explain the continuation of a glacial water-fall in one place while it was excavating one of these "Giant's Kettles" or potholes. After the ice-sheet acquired a current because of the greater thickness and pressure of its mass, such deep cylindric excavations in the bed-rock could not be made; and during the recession and final dissolution of the ice-sheet, it seems probable that its receding border had steeper gradients and consequently even more rapid motion than in the culmination of the glacial epoch."

In criticism of this view it may be pointed out, first, that while the movement of the ice-sheet was still practically *nil*, it would probably have accommodated itself to the irregularities of its rocky floor without cracking; second, that the face of the country, before it had been swept by the long-continued advance of the ice-sheet, was probably buried beneath a considerable thickness of soil and half-decomposed rock, the product of chemical and mechanical decay during long preglacial ages; and third, that it makes no adequate allowance for glacial erosion of the hard rocks during the long periods of the maximum development and waning of the ice-sheet, which would inevitably have obliterated the potholes. In short, Mr. Upham's view carries as its logical consequence the reduction of glacial erosion not only to a minimum, but almost to nothing.

While seeking for additional light upon this problem it has occurred to me, first, that a *moulin* may remain approximately

stationary, while the ice moves on, through the backward erosion and melting of its up-stream side; and, second, that when a pothole is formed at the bottom of a *moulin* it is not the direct impact of the water upon the face of the ledge that does the work, nor do the stones carried down by the water wear the ledges appreciably by their direct fall, but the pothole is due to their subsequent movement and especially their rotation by the water. This rotation implies an antecedent depression or hollow to hold the stones, and thus the conditions are seen to be essentially the same as for ordinary river potholes. Since the rotation of stones in a pre-existing hollow is an essential condition of the glacial as of other potholes, and the *moulin* simply supplies the power, it would seem to make little or no difference whether the water plunges into the up-stream side, the middle, or the down-stream side of the hollow. The pothole will be made where and only where the hollow is; and during the progress of a *moulin* across the hollow there would not, apparently, be any marked tendency to elongate it. In the case of a linear group of potholes on the lee slope of a ledge, it is reasonable to suppose that the upper one, which, on Cooper's Island, is always the smallest and most indefinite, marks the shifting position of the *moulin*, and that the others were formed by the subglacial flow of water from the bottom of the *moulin*.

Reverting once more to the question as to what phase of the continental glaciation—the beginning, the maximum, or the waning—was most favorable for the formation and preservation of glacial potholes, it may be noted: First, that during the development of the ice-sheet precipitation was mainly in the form of snow, and greatly exceeded the waste by melting; the true glacier ice was covered by a great thickness of névé and snow; the water escaped largely by seepage; and the superficial streams were small. Second, that while the growing sheet of ice, névé, and snow must have been virtually stationary for a long time, it must also have attained quite a high velocity (for an ice-sheet)

before crevasses extending up through the thick layers of yielding névé and snow to the surface could be formed; and the latter condition must, of course, be realized before glacial *moulins* are a possibility. Third, that it is in the highest degree improbable that during the period of maximum glaciation such comparatively slight inequalities as the Cohasset ledges could have produced crevasses traversing the entire thickness of the ice-sheet; just as in the case of inequalities in the bed of a river, the surface disturbance diminishes with the depth of the water. Fourth, that since the decay and final disappearance of the ice-sheet were due to a general amelioration of the climate, resulting in part it is probable from a depression of the land, it was probably accomplished by such a general ablation of its upper surface as would have caused only a slight increase in the gradient, an increase that may have been neutralized, so far as its effect upon the rate of movement of the ice was concerned, by the greater depression of the land toward the north, and the steadily diminishing thickness, weight, and power of the ice. It certainly seems more reasonable to suppose that the rate of movement of the ice-sheet diminished as its weight and power declined, than that it continued to increase until the final disappearance of the ice. Fifth, that when the decay of the ice-sheet over any area was well advanced, it must have presented, at least during a considerable part of the year, a surface of hard, brittle ice; the conditions being thus more favorable than at any previous period for the existence of superglacial streams and of crevasses traversing the entire thickness of the ice; and it is obvious that such crevasses are now consistent with a very slow movement of the ice over very slight inequalities of the ground, for the ice has lost, in its loss of weight, not only the power to flow rapidly forward, but also the power to flow around the ledges and mold itself accurately against them without rupture of its mass. Sixth, that with the diminishing thickness of the ice-sheet there must have come a time when it could no longer overcome the friction of so rough a

surface as the Boston Basin presents, and it became essentially stationary, or was subject to slight local movements only; and presenting still a fairly continuous sheet of solid ice, with surface streams and crevasses, the conditions were especially favorable for the formation of normal glacial potholes by stationary *moulins*. Seventh, the contours and distribution of the modified drift in this region indicate that the ice-sheet became, later, very ragged, being frayed out at the margin and divided into numerous detached masses, so that important surface streams and *moulins* ceased to exist. In conclusion, attention may be called once more to the fact that the glacial potholes prove by their very existence that there has been no appreciable glaciation of the rocks in which they occur since they were formed. In other words, they are a record of a time when the ice-sheet still covered the land, but had become nearly or quite stationary.

It may be remarked in this connection, also, that while the till in this region is found to lie almost universally upon strongly glaciated rock surfaces, the deposits of modified drift repose in part upon glaciated, but very largely upon unglaciated and distinctly water-worn surfaces. It is a common circumstance also to find the protruding and stoss portions of ledges from which the sand and gravel have been removed more or less distinctly glaciated, while all the depressed and lee surfaces are beautifully sculptured by water, showing many incipient pot-holes connected with winding channels and separated by smoothly hummocky and undulating surfaces. The glacial striae often end abruptly at the margins of these depressed areas, showing very distinctly the co-operation or simultaneous action of water and ice at a time when the ice had but little erosive power, and proving very clearly, also, that the water was subglacial.

MODIFIED DRIFT AND TERRACES.

It is generally conceded that the recession and final disappearance of the ice-sheet was attended by, and probably

consequent upon, a marked depression of the land. This depression was, apparently, more than sufficient to restore the preglacial relations of the land and sea; or at least evidence is not wanting that the shore-line was, for a brief period, somewhat above its present level. The re-elevation of the land here referred to amounted to 520 feet in the vicinity of Montreal, 225 feet on the coast of Maine, but only to 20 or possibly 30 feet in the Boston Basin; and the evidences for both the elevation and the slow subsidence which has since been in progress are much less perfectly developed in the Nantasket area than in other parts of the Basin.

Partly by subglacial and superglacial streams, but mainly by the great torrents and the temporary lakes resulting from the final melting of the ice-sheet, the till or bowlder clay was very largely modified, — that is, washed, assorted, and stratified in the sand plains or deltas, gravel ridges or eskers and kames, and clay beds. The explanation of modified drift in general requires a constant blending or intermingling of glacial, fluvial, and lacustrine conditions; and probably, also, in the Boston Basin, for the clay beds if not the lower deposits of sand, we may postulate marine conditions.

Among the various forms of modified drift the eskers or gravel ridges appear usually to be the oldest; and being the product, chiefly, of superglacial and subglacial streams, they evidently record the actual presence of the ice-sheet as a fairly continuous body of ice and not as the detached masses of ice indicated by the kettles and other features of the sand plains. If any important or esker-forming glacial streams crossed the Nantasket and Cohasset area, their accumulations have been effaced by subsequent erosion or deposition; for no distinct eskers have been observed. The sand plains, also, are rather scantily and imperfectly developed.

Sand plains, in general, we must regard in part as representing the flood-plains of great rivers flowing from the melting ice-sheet and in part as deltas formed by these rivers in temporary

lakes or, possibly, in the case of the lowest plains, in the sea. Most of these lakes were undoubtedly truly glacial,—that is, enclosed partially, sometimes wholly, by solid walls of ice. The kettles, dimpling the sand plains, it is well understood, are due to the subsequent melting of masses of ice which were buried in the stratified deposits; and the steep and sharply-defined marginal slopes which the sand plains often present are doubtless in part the natural, free, growing edges or fronts of the deltas, and in part due to the subsequent melting of walls of ice against which either flood-plain or delta deposits had been accumulated, the sand and gravel, as it was thus gradually let down, naturally assuming the maximum declivity.

The Nantasket Peninsula, being then surrounded by deeper water than at present and even more remote than now from the main land and the mouths of rivers, was almost exempt from these delta and flood-plain deposits. The higher plains are entirely wanting here, and the lowest, which varies usually from fifteen to twenty-five or thirty feet in height, is developed in only a very scanty and fragmentary manner, as on the south side of Point Allerton. In Cohasset and Scituate the plain, having usually a height of from forty to sixty feet, is well developed at intervals. It forms the comparatively level land along the railroad between Hingham and Cohasset Village; and in the northern part of the village, and especially between Little Harbor and the railroad, it is a very typical plain, this part of the village being designated as the "Plain" on the published maps of the town. It rises quite abruptly 45 feet from the marshes of Little Harbor and, deeply dimpled with beautiful kettles, slopes gently down on the south to the marshes and James River. One of the kettles, on the north side of Beach Street near the Plain, has long been known as the "Punch Bowl"; and several of them hold permanent ponds, the pond near the south end of the Common being an example. When this plain was formed, the ice must have completely filled the basin of Little Harbor; and the stream supplying the detritus probably

came from the west or northwest. It is interesting to observe that this deposit of sand is probably the only barrier between Little Harbor and Cohasset Harbor at this point.

The considerable deposits of modified drift in the Beechwood district, south and southeast of Scituate Pond, may be regarded as a fragmentary development of this plain. A much lower plain, which, quite probably, is of marine origin, has a very perfect development in the district south of the Glades. It terminates on the east in Mitchell's Beach and presents a very flat, unbroken surface, from 10 to 15 feet above the sea, over an area nearly half a mile square. It is also scantily developed along the northern edge of the peneplain, in the vicinity of Rockland Street, and at other points; and we may reasonably suppose that farther inland it underlies the broad, level, and swampy valley of Bound Brook and its tributaries.

Beds of clay, or the finer portion of the modified drift, appear to be wholly wanting above sea-level in the Nantasket and Cohasset area. There can be but little doubt, however, that they are extensively developed under the salt marshes and in the drowned or marine portions of the valleys generally. The slow development of the salt marshes during post-glacial time probably commenced in every important instance with a broad, level expanse of the finest glacial silt or clay covered by a moderate depth of water and supporting a luxurious growth of eel grass. In the meshes of this dense jungle or mat of vegetation the detritus brought by the tides is entrapped and slowly sinks to the bottom. The upper surface of the deposit is thus slowly raised to the low-tide level, when the conditions become unfavorable for the growth of eel grass and the area enters upon the mud-flat stage. Although the main sweep of the flowing and ebbing tides is now through more or less definite channels or creeks, but little additional silt lodges on the unprotected flat until it has been overrun from the shore outward by higher forms of vegetation, when the silting-up process proceeds unchecked until the high-tide level is reached. A dense, firm

mat of peat-forming vegetation then covers the surface, and the marsh is complete. In other parts of the Boston Basin, however, and generally wherever excavations have been made in the salt marshes, the evidence is conclusive that a slow subsidence has permitted the formation of several successive beds of peat, separated by beds of clay.

Although, as the beaches, marshes, and marine cliffs so plainly indicate, the sea has undoubtedly maintained its present level for a very long time, the rocks of our coast are so intensely hard and resistant that there are very few points where they show any appreciable amount of marine erosion. All along the Nantasket and Cohasset shore it is perfectly obvious that, save where the rocks are very finely jointed, or a dike has yielded to the ceaseless pounding of the waves, the ledges are still essentially intact, showing still the *roche moutonnée* forms impressed upon them by the ice-sheet, even the glacial striae being, in some cases, well preserved for several feet below the high-tide level.

Above the present level of the shore evidences of marine erosion on the hard rocks are, so far as I have observed, wholly wanting. If the sea has stood at higher levels in post-glacial times, the evidence must be sought in the erosion, not of the hard rocks — granite, felsite, melaphyr, etc., but of the non-lithified or drift deposits. Fortunately, the drumlins, which are such a prominent feature of Boston Harbor, present in their firm but yielding material and regular outlines conditions exceedingly favorable for making and preserving a record of even a very brief occupation of a higher level by the sea. Any one who notes the extensive erosion of the drumlins by the sea at its present level and the comparative stability of the erosion scarps, cannot doubt that if similar features — terraces and scarps — had ever been developed on the drumlins at higher levels, some indications of them would still be traceable. A general study of the drumlins of the Boston Basin has satisfied me that undoubted horizontal erosion-marks are a common

feature up to a height of 100 feet or more above the sea. They exist as strongly-marked and approximately horizontal and longitudinal scarps and terraces, frequently bearing bowlder pavements and showing a general correspondence in height with the sand plains of the region. They have been observed in all parts of the Boston Basin; but are, perhaps, most favorably exposed for study on several of the drumlins northeast of Boston, including Breed's Hill, Pleasant Hill, Mt. Revere, Mt. Washington, and Powder-Horn Hill. They are also a prominent feature of several drumlins on the South Shore, including Baker's and Otis Hills, in Hingham, and have been observed on some of the drumlins of the Nantasket-Cohasset area. These may be briefly described, commencing on the north.

On the southwest side of Telegraph Hill, in Hull, a sloping, bowlder-strewn terrace, from 20 to 30 feet above the sea and backed by a steep declivity, extends directly across from shore to shore. The only terraces on Point Allerton Great Hill are such as have probably been formed by the gradual accumulation of soil by rain-wash against stone walls at the lower edges of cultivated fields. Three such artificial terraces may be readily traced along the southern slope at heights of from 55 to 75 feet. The 20- to 30-foot terrace is well developed on the south and southwest sides of Sagamore Hill, opposite the steamboat wharf, and it may be traced along the southwest side of the northern drumlin of World's End. A strongly marked terrace extends for a short distance on the northeast side of Planter's Hill, at a height of 55 feet. Occasional indications of terraces have been noted on the southwestern slopes especially of other drumlins in Nantasket and Cohasset, including Strawberry Hill, Bumkin Island, Turkey Hill, Scituate Hill, etc. But the only others requiring particular description are the series on the northeast side of Booth Hill, in Scituate.

This great drumlin extends southeast from Bound Brook, near North Scituate, for about one mile. Its northern base is closely skirted by the railroad, and on this side it immediately

Fig. 23.—Hatch's Rock, on Booth Hill, in Scituate.

overlooks the salt marshes tributary to the Gulf. Going up from the marsh we come, at a height of 25 feet, to a distinct and level terrace, which is several hundred feet wide midway of the length of the hill, where the church stands upon it, but narrows toward either end. The road running from the church over the hill rises, at the cemetery, 15 or 20 feet to a well-defined terrace and bowlder pavement from 100 to 200 feet wide. In the vicinity of the church the main highway between North Scituate and Scituate Harbor runs on the lower terrace. But farther west, near the school house, it rises to the second terrace. From the school house a private road ascends the hill and brings us at a height of about 30 feet (70 feet above the marsh) to a third terrace, which is at least 300 feet wide and thickly strewn with bowlders. This terrace cannot be clearly traced so far east as the highway across the hill; and like both the others, it dies out near the west end of the hill. Following the private road about 30 feet higher (100 feet above the marsh) we come to a broad, level plain, which seems at first to form the summit of the hill; but on tracing it eastward

across the highway the hill is found to rise abruptly some 20 feet above the plain to the true summit, on which Hatch's Rock (Fig. 23) stands. The plain is here at least 300 feet wide; and at all points, save where it has been cleared for cultivation, it is strewn with bowlders. From this terrace the view seaward is broad and unobstructed; and if the sea has ever stood at this level since the drumlin was formed, its storm waves must have broken with such resistless force against the banks of till as to require only a short time to carve this broad platform.

Several of the lower drumlins of this region, which show no terraces—Green, Hoop-Pole, and Mann Hills—are so flat-topped as almost to suggest that their original summits have been worn away by the sea or some agent of horizontal erosion.

The lowest terraces on the drumlins consist chiefly and the upper ones to a very limited extent of modified drift, being, properly, narrow, fringing sand plains. But that the drumlins of this region also exhibit many true terraces of erosion, and that these are in many cases of such magnitude as to profoundly modify the normal contours of the hills, there can be no doubt or question. Concerning the origin and real significance of the cut terraces, however, there is still room for the widest difference of opinion. As stated in the general description of the topography (page 7), I at first regarded these terraces as true shore-lines, and for the most part as marine shores, finding in them evidence of an important postglacial elevation of this coast. But a more extended and critical study of these features since the printing of this work began has convinced me that, as already pointed out, they lack the essential characteristics of true shores. They are not only deficient in continuity and uniformity of level; but it is further impossible to regard them as marine shores, because, with rare exceptions, like Booth Hill, they are on the southwest sides of the drumlins and do not face the sea; or as the shores of temporary lakes, because they are often, as in the Village of Hull and on the World's

End, in very narrow valleys between the drumlins, that is, in the most sheltered spots, where we would least expect erosion by waves. Still another difficulty in the way of regarding them as ordinary shore-marks is the fact that they occur only on the sides of the drumlins, the scarps never, so far as observed, changing their directions so as to cut across the ends of the hills. That is, they notch or break the transverse, but never the longitudinal, profile of the drumlins. We may safely conclude, then, that they have not been formed in or by standing water.

It has been suggested to me that the terraces may, perhaps, be regarded as original features of the drumlins, owing their formation to the molding action of the moving ice, the drumlins having been grooved or fluted by the ice on a large scale. This explanation would account for their uniform parallelism with the major axes of the drumlins; and I am inclined to believe that some of the less distinct terraces are really gigantic glacial grooves, formed, of course, while the ice still covered the drumlins, and not by the edge of the ice, since it is probable that when the ice had melted sufficiently to uncover the tops of the drumlins its motion had practically ceased. Starting with the normal type of drumlin, we recognize departures from it in several directions. Thus some are long and narrow or ridge-like, while in others the longitudinal and transverse axes are nearly equal, and still others, though presenting the normal proportions of length and breadth, are unusually flat-topped, like Booth Hill and many of the lower drumlins, including Hoop Pole and Green Hills. These variations are probably original and due in part to the contours of the underlying ledges and the character of the till and in part to the varying thickness and motion of the ice; and no reason is apparent why the latter cause, at least, may not give us departures from the regular curvature of the transverse profiles.

As a rule, however, the terraces are too deeply incised and much too sharply defined to be explained in this way. It is

highly improbable that in the case of a terrace due to glacial molding we should pass abruptly, over a well-defined edge, from the steep erosion slope or scarp behind the terrace to the normal slope of the drumlin above the scarp; for it is inconceivable that the erosive action of a continuous sheet of ice could be so sharply differentiated. The scarps are not simply a little steeper than the normal slopes, but they are in most cases as steep as the material will maintain, as steep and sharply defined, in fact, as the scarps of till on the modern shore which have been protected for a few years from the action of the sea.

We are thus, apparently, forced to refer the terraces to the erosive action of running water. It is improbable that strictly subglacial streams would cross the drumlins at all; and if they did, the natural result would be to produce channels rather than terraces. The same would be true of superglacial streams, wherever they cut through the ice into the underlying drumlins; and such channels, notching their summits, have been observed on some of the drumlins of eastern Massachusetts. The only alternative view that now seems worthy of consideration is that which refers the terraces to the erosive action of lateral streams. When the ice had retreated from the summits of the higher drumlins and, presumably, had ceased to flow, the heat reflected from the ground would naturally melt away the edge of the ice sufficiently to afford pathways for the superglacial streams, and drainage channels for glacial waters impounded north of or behind the drumlins. These lateral streams, having banks of ice on one side and till on the other, would necessarily erode the latter in the manner indicated by the existing terraces. This explanation accounts for the longitudinal direction of the terraces; for the observed irregularities in height and level; for the accumulations of modified drift sometimes observed at the eastern ends of the terraces; and especially for the occurrence of the terraces chiefly on the southern slopes of the drumlins, since it is on these slopes that the heat of the sun would be

most effective in melting away the ice, the surface of which would naturally slope toward the drumlins. The terraces are thus a joint product of glacial and fluvial conditions, contemporaneous with the modified drift; and like that record the rapid waning of the ice-sheet when it had ceased to flow but yet lingered in the valleys. Some gullies or vertical erosion channels appear to have been formed on the drumlins at this time; and probably the many other depressions and hollows observed on their slopes, which are often ill-defined, but commonly somewhat saucer-shaped, are the result, chiefly, of local landslips dating from this period when the till was first laid bare and was yet unprotected by vegetation.

THE MODERN SHORE.

When the sea finally retired from its highest postglacial level, it appears to have subsided quite rapidly to a level somewhat below the modern beach. Evidence that the land has recently stood higher than now is found at other points in this region chiefly in the form of submerged peat beds and forests, and the former, at least, would probably be found if excavations were made in the Nantasket marshes. Although the depressions occupied by the marshes and the winding channels of Weir River Bay, Strait's Pond, etc., are clearly submerged land valleys, as previously explained, their origin — the erosion of the hard rocks — undoubtedly dates from the strong elevation of the land at the beginning of the ice-age. In fact, it is not in land erosion, but in the absence of marine erosion at certain points where it might otherwise be expected to exist, that the evidence sought for is to be found. It is a fact familiar to all that the drumlins of the harbor exhibit marine erosion wherever freely exposed to the sea. This erosion scarp exists, in general, not only on the seaward, but also, in less degree, on the landward, sides of the drumlin islands. Being the work, almost exclusively, of the waves, it varies somewhat with the

breadth and depth of the water, and is most marked on the sides of the prevailing winds. It is, however, almost entirely wanting on the eastern ends of Thornbush and Telegraph Hills, Little Hog Island, Bumkin Island, the western part of White Head and Hampton Hill, as well as the eastern shores of World's End and Planters' Hill. At present, of course, these points are bordered by shallow water and, what is still more important, they are in the lee of Nantasket Beach, and are thus protected from the ceaseless beating of the ocean swell. It is perfectly clear, however, that this broad beach has been formed *since* the existing relations of the land and sea were finally established; and if the postglacial elevation of the land had ceased when the present level was gained, the sea, sweeping freely through the broad passes between Strawberry Hill and Point Allerton on the north and White Head on the south, and the narrower gaps still further south, would inevitably have worn away the eastern ends of the masses of till which now enjoy the protection of the beach. Considerable and, at some points, ineffaceable results would undoubtedly have been accomplished before the sea succeeded in throwing up the barrier beach that now checks its own depredations. The absence of sensible erosion at these points is, however, readily explained, if we admit that the comparatively rapid elevation of the land probably continued until it stood somewhat higher than at present; and that a slow and gradual subsidence has since been in progress. Whenever, during this subsidence, the depressions between the drumlins of what is now the Nantasket Peninsula were brought within reach of the waves, barrier beaches were naturally formed across them; and these barriers have kept pace in their upward growth with the subsidence, so that the land behind Nantasket Beach has been continuously protected from the action of the surf. This view relieves us of the necessity of imagining a cordon of drumlins outside of the present beach which have been completely washed away, although it is not improbable that Harding's Ledge and the

Black Rock Islets are the foundations of such vanished drumlins.

It is obvious to the most casual observation not only that the present shore is strongly marked in all its various features, but also that its level has been unchanged for a long time. This is seen especially in the essentially finished state of the salt marshes, which, over broad and continuous areas, have clearly attained their maximum elevation—extreme high tide; and in the great breadth of Nantasket Beach. The front of the beach, when it was first established, probably formed a series of rather strongly concave curves connecting the drumlins, all of which were then fully exposed to the surf. The over-wash of the beach at this time formed what is now its rather low and marshy inner margin; while through the additions made by the erosion of the drumlins the line of the beach has been gradually straightened and advanced seaward until Strawberry Hill and the drumlins south of it, although their sea-cliffs are still sharply defined, are separated and protected from the breakers by a wide belt of sand and shingle. The Point Allerton drumlins are still within reach of the waves. The little hill would probably have been completely swept away by this time but for the massive sea-wall which has been built around it. Its present area is less than two acres, but it probably extended once as far as the beacon and had an estimated area of forty-five acres—as large as Boston Common. Between 1847 and 1860 its cliff receded 65 feet, equal to the loss of half an acre. The great hill has lost an estimated area of fifteen acres, but the outward growth of the beach has now nearly stopped the erosion. The finer material washed from the north side of Telegraph Hill has been carried to the westward to build Windmill Point, which is a miniature Cape Cod. In like manner the waste of Green Hill, and possibly of other drumlins which once existed in that vicinity, has formed the barrier beaches between Strait's Pond and the Atlantic; and even the widest of these, Crescent Beach, is still so narrow that

it grows chiefly by over-wash during great storms. The same is true of the barrier beaches separating Little Harbor from the open sea, and those on the Scituate shore. The supply of fresh material being now virtually cut off, the outward growth of the beaches must substantially cease or the additions consist of much finer material, such as might be brought from more distant sources. The increasing fineness of the sand on Nantasket Beach is apparent from the fact that distinct sand dunes may now be seen along the front of the beach north and south of Strawberry Hill, having a height in some cases of ten feet or more, while they are entirely wanting on the back side of the beach. At the south end of the beach the sand is also very fine, and abundant traces of it may be observed at heights of from 20 to 30 feet on the north side of Atlantic Hill; while in the valley between Atlantic and Willow Ledge Hills a considerable bed, not of modified drift, but of the same fine white beach sand may be traced as far south as Atlantic Avenue. The accumulation of beach sand in this sheltered spot does not appear to be in progress now. But, although it could be used as an argument for the recent elevation of the coast, I am disposed to ascribe it to strong northerly winds in past years.

Supplement.

During the time that has elapsed since the printing of this work began, some additional observations have been made which, although not involving any material changes in my views concerning the geological structure of the region, it is thought best to indicate briefly, in order to make the exposition of facts as complete as possible.

Besides the two small granite quarries on the Cohasset and Scituate shores, referred to on page 17, there is a third quarry on the south side of Scituate Hill which has afforded some good stone for general use.

Undoubtedly the most interesting flow of melaphyr in the Nantasket district is the second melaphyr in the Valley Beach section described on page 52. This flow is of particular interest, not alone because it can be traced in one direction to a distinct edge, but also on account of the numerous, irregularly rounded, amygdaloidal masses which it incloses. I have referred to these masses as pseudo-bombs; but, although well satisfied, as stated, that they are not true volcanic bombs, or projected masses of lava, it is very gratifying to find this view confirmed by the observations of Prof. J. D. Dana on the lavas of the Hawaiian Islands; and I am grateful to Mr. Geo. P. Merrill for calling my attention to the following statements by Professor Dana.[1]

The *aa* streams are remarkable also for the presence of lava-balls of concentric structure that have been wrongly called bombs. These lava-balls are smoothish exteriorly, more or less rounded and bowlder-like, and vary in size from an inch or less to ten feet and more.

Some of these lava-balls have, outside, a crust of hard lava, and, inside, fragments of scoria; others consist of concentric shells, hard and scoriaceous shells alternating with one another.

[1] Amer. journ. sci., 1887, ser. 3, vol. 34, p. 364.

One on Hawaii, near Punaluu, was found to have a nucleus of scoria eighteen inches in diameter, and around this successively a stony shell of three inches, a scoriaceous layer of from one to two inches, a stony shell of from four to five inches, and then outside a rough lava shell six inches thick. One of large size, broken open on one side, had had its inside filling of scoria worked out by the natives, and so made into a small cave. A common size on Hawaii is from three to five feet in diameter; but one enormous lava-ball, in the *aa* field west of Punaluu, measured 24 by 12 by 9 feet in its extreme dimensions, and contained at least a thousand cubic feet. Enough of its hard outer shell was peeled off to ascertain that the second layer was quite vesicular or scoriaceous, and the next layer inside hard basalt again. These Hawaiian lava-balls lie in the midst of the other blocks of the *aa* stream, proving that all had a common origin, and that they are not projected bombs, and hence properly not bombs at all.

Professor Dana[1] also refers in the following terms to the paper on "Fragmentary ejectamenta of volcanoes" by Dr. H. J. Johnston-Lavis[2], who has studied with much care the Vesuvian lavas and eruptions. He (Johnston-Lavis) shows that the "volcanic bombs" of writers on European volcanoes are not bombs any more than those of Mt. Loa; that they were not projected into the air; that they occur scattered over lava streams in great numbers when the adjoining country is free from them, and occur within lava streams; that they vary in size from a walnut to some cubic yards, and yet have often a thin shell and friable nucleus; that they occur most commonly by far on lava streams whose surface is rough and scoriaceous instead of corded. He regards them as formed of lapilli that fell upon the flowing lava, and, in consequence of its forward motion, became incorporated with it, and may undergo partial fusion, but usually congeal around themselves a coating of the lava in which they are involved. Dr. Johnston-Lavis

[1] Amer. journ. sci., 1888, ser. 3, vol. 36, p. 103.

[2] Proc. geologists' assoc., London, vol. 9, no. 6.

also points out that the *ejected blocks* of solid lava are wholly different in origin, and readily distinguished from the so-called volcanic bombs.

The red slate referred to on page 55 as outcropping on the edge of the marsh, west of the Rockland House, is probably not a tuff; but it appears better to regard it as a slaty layer in the conglomerate. A similar layer occurs in the conglomerate south of Willow Ledge Pond; and, without wishing to suggest the exact correlation of these very limited deposits of finer sediment, it has appeared best, on the map, to indicate the conglomerate in the vicinity of the pond as extending westward far enough to embrace the second outcrop of slate.

There appears now little reason to doubt that the large outcrop of hard, slaty rock on the railroad, west of the Rockland House, is a true tuff; and it should probably, in spite of its finer texture, be correlated with the main bed of tuff at the base of Atlantic Hill.

In the description, on page 67, of the faults crossing Crescent Hill, it should have been noted in connection with the third fault, which accompanies the small dike, that the dike itself marks a fault plane of later date than the other and compensating with reference to it. The two faults hade in opposite directions, and the only displacement of the strata actually observable is the elevation of the triangular mass of melaphyr between the two faults. It now appears probable, also, that there is one more fault on the southern slope of Crescent Hill than has been described in the text; and it has been so represented on the map.

There appears now no sufficient reason to extend the fault which is supposed to cross the western end of Conglomerate Plateau southward to the granite and the boundary fault, as suggested on page 74; and it has not been so drawn.

The position of the conglomerate overlying the melaphyr south of Conglomerate Plateau and east of Round Hill appears to be slightly synclinal, probably rising both to the east and west.

It now appears improbable that all of the contacts of conglom-

erate and melaphyr in the area between Hull Street and Strait's Pond are due to faults, as stated on page 75. The more probable view is that expressed on the map, *viz.*, that the alternate contacts are faults. The conglomerate of Round Hill and Conglomerate Plateau, with a gentle southerly dip, is overlain by the second melaphyr; and the outcrops of these two beds are repeated several times by east-west displacements downthrowing to the north.

Recent observations have thrown additional light upon the relations of the dikes of the central belt in the vicinity of Hull Street; and nearly all the dikes in the section on the railroad can now be traced across Conglomerate Plateau. Nos. 25 and 27 are clearly the same dike; and this can be traced now, as shown on the map, to the intersection of Hull Street and Atlantic Avenue. Just west of Hull Street it appears to cross the course of 29; and what appears to be a branch from the latter quite clearly cuts 25 on the north side of Hull Street, and then runs parallel with it. No. 31 also branches near Hull Street; but there seems to be no way of definitely deciding whether the dike which ultimately reaches the shore of Strait's pond is 29 or 31. No. 24, on East Porphyrite Hill, is clearly a continuation of 38, on Granite Plateau; and there is a clear path for it across Cliff Plateau, although it does not appear to be actually exposed.

For the elevations of some of the drumlins in Cohasset I am indebted to Mr. H. W. Nichols, a student in the Geological Department of the Massachusetts Institute of Technology; and for many of the names on the maps I am under obligations to Col. E. T. Bouvé. He has prepared a very interesting chapter on the ancient land-marks of Hingham and Cohasset for the forthcoming history of Hingham, and has kindly permitted me to use the proof-sheets.

I also gladly embrace the opportunity which this supplement affords to acknowledge the important aid in the prosecution of this work which I have received during the past year from Mr. Thomas A. Watson. He has not only made possible a great

economy of my time while in the field; but he has proved himself an unusually acute and accurate observer, with a ready and clear comprehension of the bearings of nearly every new fact; and my work has been at some points materially strengthened by the data and conclusions which he has freely placed at my disposal.

GEOLOGY OF THE BOSTON BASIN, BY W. O. CROSBY. GENERAL MAP, SHEET 1.

Scale 1/28,800 or 1 inch = 2400 feet.

600 1200 2400 4800

One Mile.

Outcrops of Diorite. | Important Bowlders and Ledges. | Granitic Rocks, (Granite, Diorite, and Felsite.) | Conglomerate Series. | Newer Slate. | Metaphyr. Porphyrite, and Tuff. | Outlines of Drumlins. | Kames. | Salt Marsh. | Fresh Marsh. | Kettle-holes. | Faults.

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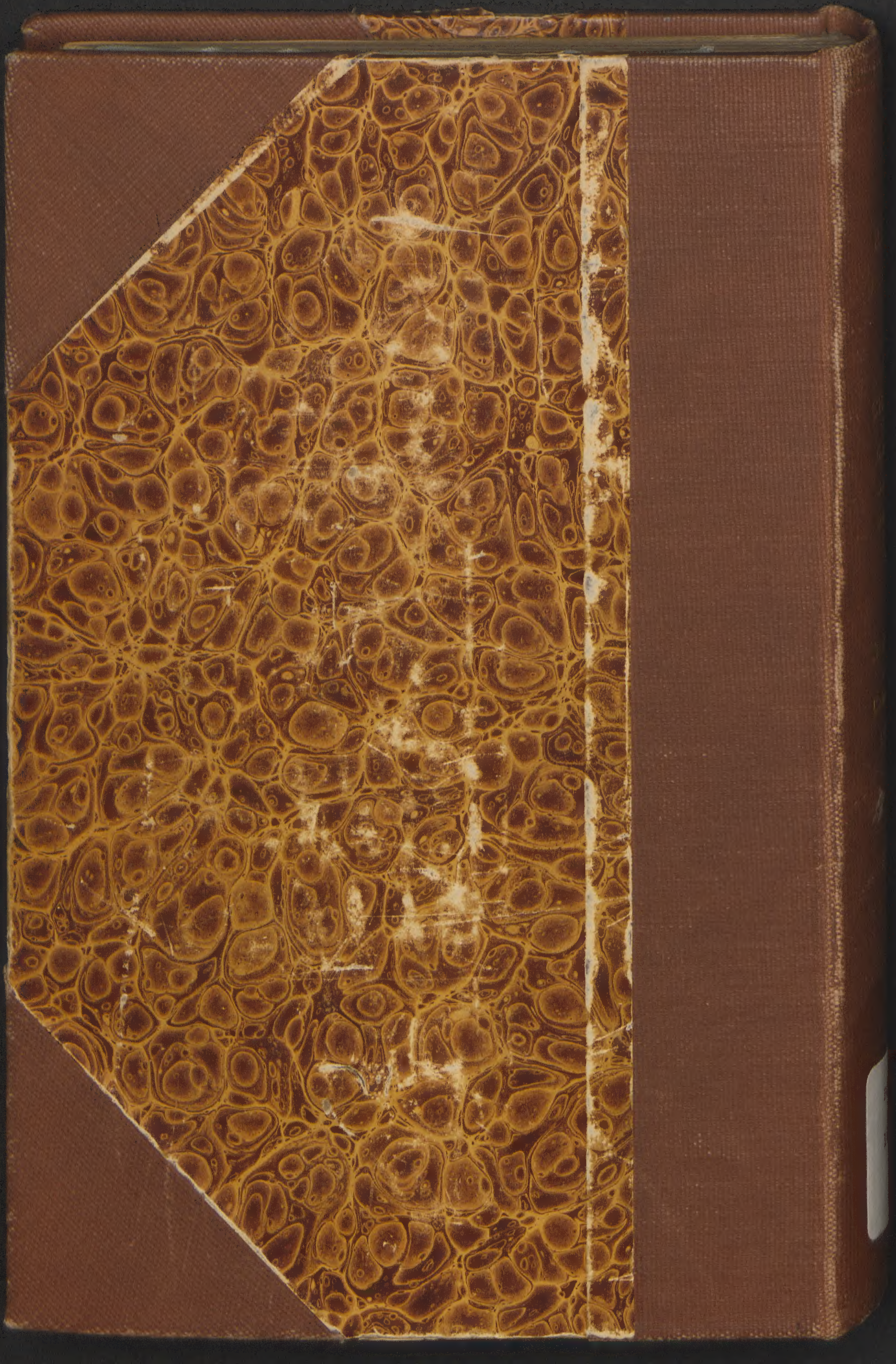
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